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Foreword

Environmental indicators – friend or foe?

In the 40-plus years I have been working for better environmental outcomes, the role of indicators and their relationship to environmental targets has been a recurring theme. If you want something to happen, so the thinking goes, set a target. Then everyone knows where they stand and there is collective purpose in meeting it. If we get indicators right, they help us understand if we are on track.

In the very early 1980s, governments did not prioritise setting environmental targets, and as environmentalists our priority was to get the environment recognised at all. Most of our efforts were devoted to policy: for example, stopping agricultural grants that rewarded farmers for pulling out hedgerows and draining ponds, as well as challenging and mitigating the impact of big infrastructure projects on the environment, like road and energy schemes.

That all began to change as the EU – which we had joined in 1973 – stepped up its environmental ambitions. Arguably, it was the EU that was the main driver for environmental improvements in the UK in that period, and it was indeed the clear targets it set (with our agreement) that focused action and progress. Chris Patten's 1990 environment White Paper *This Common Inheritance* was an attempt by the UK Government to seize the initiative at home, and it established a broad political consensus domestically (if too slow action) that the environment is important to everyone.[1]

Following the ground-breaking introduction of the Climate Act 2008 and reinforced by the 2015 Paris Agreement, UK carbon targets gained traction. But the recent abandonment of the 2050 net zero target by the Conservative Party, and President Trump's public withdrawal from the Paris consensus may well lead to a crumbling of effort and slippage of progress globally.

Indeed, as this issue's articles show, environmental indicators and the targets that they enable have a mixed track record. Those set by the UK Government in its Environmental Improvement Plan are invaluable, and after many years of pressure there is now a dashboard for chemicals at European level. Denmark, for example, is using a complex pesticide load indicator to track toxicity introduced by pesticides. However, we are still working out what the appropriate indicators are in important areas like environmental sustainability and the circular economy. And in the important area of beauty (a personal passion of mine) we risk missing the point if we do not understand the cultural significance of beauty in our race to quantify environmental ambitions.

Today we are positively dripping with environmental targets set by indicators, but making at best poor progress against them, as the Office for Environmental Protection reports annually. As we have learned, going down silos to chase a target may have unexpected consequences and even perverse effects. Maybe the time has come for an approach based on integrated outcomes, striving to achieve healthy, thriving, whole ecosystems rather than multiple narrow targets.

REFERENCES

1. HM Government (1990) *This Common Inheritance*. London: HMSO.

Dame Fiona Reynolds chairs the National Audit Office, the Council of the Royal Agricultural University, the Cathedrals Fabric Commission for England, the Food, Farming and Countryside Commission and is a trustee of the Grosvenor Estate. This follows a long career in the environmental movement, including serving as Director-General of the National Trust.

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Cover design: Ron Watts is a Lead Designer at White Rabbit Projects. As a creative, his work is guided by a way of identifying and forming relationships between ideas and reality. He has a true passion for modular systems and is determined to keep designs simple, powerful and effective.

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Do we need environmental indicators?

Julie Hill reflects on the reasons why they are crucial for understanding and managing our impact on the environment.

We need environmental indicators simply because if we cannot measure something, we cannot manage it.

It is sobering, as I reflect on my 40-year career, that it is only comparatively recently that we have been interested in managing our impact on the environment in a comprehensive way. Which in turn means that our attempts at measuring are in some cases quite new and still not fully developed. The science and politics of indicators is still an emerging field.

Environmental indicators are crucial for governments, businesses, financial institutions and everyone interested in progress. They are especially important for environmental scientists, as often we hold the key to illuminating the trends, both concerning and reassuring. Therefore, we should all be continually asking ourselves whether what we are measuring or addressing or monitoring or evaluating are the most important parameters, or if we are simply looking at what is easy.

INDICATING RIGHT

My first detailed exploration into indicators was in 1999, in the wake of the shocking (to me) sight of one of England's largest landfills. I was working for thinktank Green Alliance and was on the advisory board of one of the major landfill companies. To that company's credit – as landfill was at that time the most economic and therefore dominant option for waste disposal (a situation later radically changed by the introduction of the Landfill Tax) – the leadership team agreed to my proposition that Green Alliance examine how landfill could be done better. This involved looking at the possible impacts of landfill and deciding how they might be measured, eventually resulting in a set of performance indicators.[1]

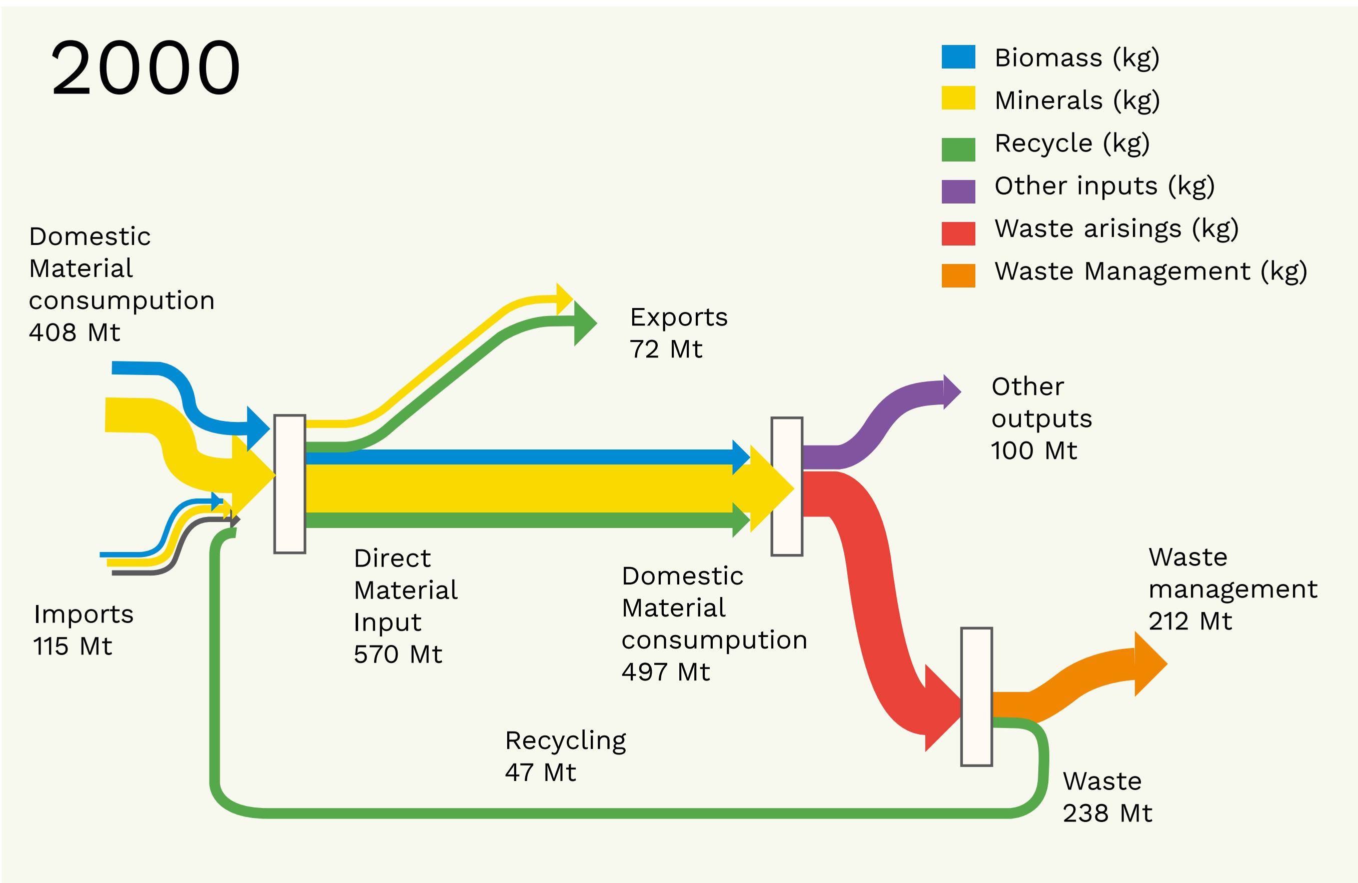
The rationale we laid out was that a set of indicators agreed across the landfill industry would offer a consistent means of reporting progress, provide measurements readily understandable by stakeholders and work towards comparability of data across companies. This was the external value – but even more important, in our view, was the internal value: identifying the most significant impacts to focus resources, clarifying environmental goals and effectively communicating them and the progress made towards meeting them to employees.

In my view, this remains a sound rationale for any company's approach to indicators. Thirty-five years on, we have a plethora of company reporting requirements, but if a set of indicators can pass these tests, they will be of value.

WASTE NOT, WANT NOT?

Waste, and its root cause, consumption, are particularly tricky things to indicate, as we explore in this issue. The landfill experience took me into a long preoccupation with waste and consumption, including physical, cultural and psychological dimensions. At a simple level, most people would agree that waste is bad. 'Waste' is a technical term: it appears in official statistics almost as a fact of life, but it is also synonymous with failure of control and with profligacy, as a glance at many local politicians' campaign leaflets will confirm.

But there are times in my career that I have had to explain what is wrong with waste – including to a Treasury official who observed that waste is good business. Those tonnes of stuff have come into the economy and contributed to gross domestic product, and going out they quite often contribute to it again through treatment and disposal. David Milliband, as Secretary of State for the Environment in the first decade of the 2000s,



▲ **Figure 1. Material flows in the UK economy in the year 2000. (Source: Sankey Diagrams, 2013[3])**

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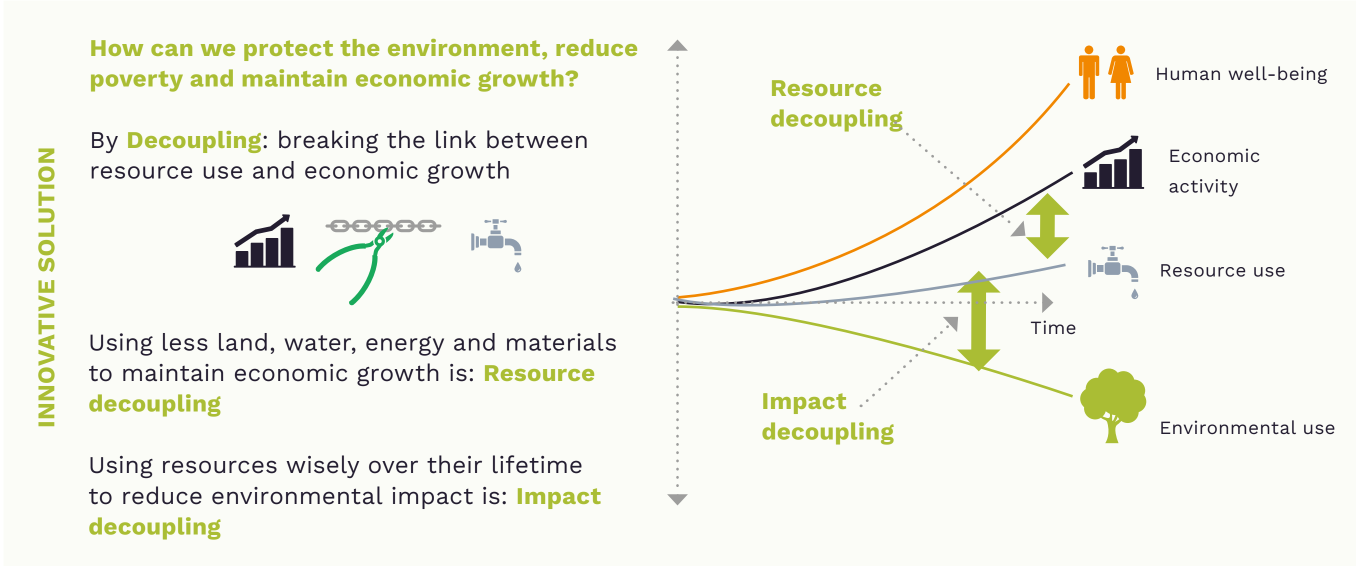


▲ **Figure 2. Decoupling resource use and economic growth. (Source: United Nations Environment Programme, 2011[3])**

was the first politician I heard articulate the link between waste and climate change: all those wasted tonnes are also wasted carbon. And water. And precious minerals. The message was getting through, and on the back of those indicators of the problems that waste causes, the concept of the circular economy was being seriously examined.

Nonetheless, the effort to properly account for those impacts has been a long, arduous road, and we are still grappling with how to measure the circular economy. A pronouncement that a country is, say, 9 per cent circular is obscure as an indicator to most people. At the same time, there is something in the imagery of the circular economy diagrams (from the Waste and Resources Action Programme in **Figure 1**, the Ellen MacArthur Foundation and others) showing the relative size of flows in and out of the economy, and the 'thin green line' that is recycling that has shocked, inspired and motivated. Sometimes a picture is worth a thousand words, even if it lacks firm numbers.

A different way of indicating progress is perhaps more process-based and looking at what instruments have been deployed to address a problem. Green Alliance did this in 2002.[2] At the time, the UK was near the bottom of the EU domestic waste recycling table at 11 per cent – which was an eye-catching indicator in itself – and it seemed that other countries had far more policies deployed (laws on separation of wastes, taxes, bans) and better records. So did the *number* of policy instruments correlate with the level of success? Not necessarily. The research showed that Flanders at 63 per cent had achieved nearly twice the recycling rate of Denmark, and each had eight policy measures in place, often the same ones.[2] Clearly, this was too crude an indicator, as the policies would not have had equal force or perhaps equally assiduous application. However, asking the question in this way drew the landscape effectively and brought to the surface a great many illuminating factors in what successes had been achieved.

CONSUMING PASSIONS

The ultimate indicator of success in addressing consumption is, in my view, the decoupling of resource use and economic growth articulated by the United Nations (see **Figure 2**).[4] This simple diagram expresses the human need for enhanced well-being for many parts of the world, a situation that inevitably involves consuming more resources, but divorcing the impact of those resources from environmental damage.

Which begs a host of difficult-to-measure questions: which resources are more, or less, good? On what measures? In what combination? How much impact is acceptable or not? How do we measure well-being? These are political and social questions, not just technical ones. As environmental scientists we can contribute data and insight, and express opinions, but we cannot make the ultimate decisions.

The psychology of indicators has also long intrigued me, particularly the effects of good news.

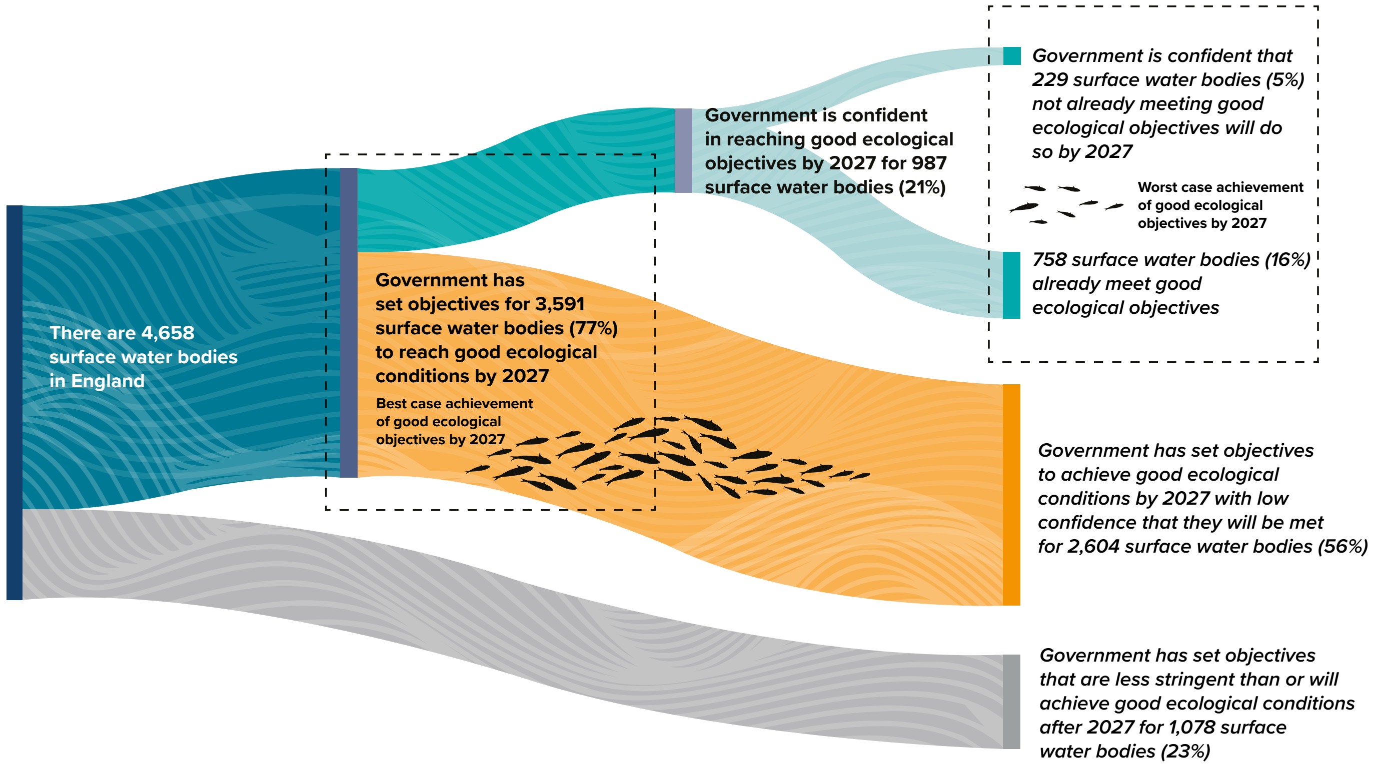
The irrepressible Hans Rosling set the standard with his animated map of global development and his book setting out how much better off a lot of the world is today compared to the 1950s.[5,6] Unfortunately, his good news was tempered by the observation that we would be doing really quite well if it were not for climate change. Inspired by Rosling's approach, data scientist Hannah Ritchie set out to provide good news for a new generation in her book *Not the End of the World*.[7] Yes, some stuff is bad, but a lot is better than it was, and much is going in the right direction – just look at the trends. I did not agree with all her interpretations of the indicators, but overall she did cheer me up. I hope that many environmental scientists will have taken to heart the message that indicators can lend hope as well as concern.

INDICATORS TOWARDS ACTION

As Fiona Reynolds reflects in her foreword to this issue, indicators and targets must go hand in hand. Without indicators of environmental states and trends, we cannot set meaningful targets. And without indicators forming the basis of ongoing monitoring, we will not understand to what extent we can hope to meet targets – and ultimately, whether the targets we have set are the most important ones to pursue.

The idea of a national environment plan emerged in Europe in the 1980s with the Dutch National Plan acknowledged as the first in 1989.[8] The UK followed in 1990 with the publication of the white paper *This Common Inheritance*.[9] This early attempt to set out a long-term, comprehensive plan was welcomed, and indicators began to be developed. But when the UK parliament's Environmental Audit Committee assessed the prospect of a new strategy under a new government in 1998, it concluded that:

'Although by 1997 the last Government had agreed 41 key targets in the range of their strategic policy documents, together they did not appear to reinforce a coherent strategy. ... Nor did they relate directly to the Government's preliminary set of Sustainable Development Indicators.'[10]



▲ **Figure 3. Indicators as scenarios: a good example of communicating complex statistics in visual form. (Source: Office for Environmental Protection, 2024[12])**

Closing that gap between targets and indicators is a mission that has been ongoing ever since, one scrutinised by the Office for Environmental Protection (OEP), as Cathy Maguire lays out in her article. The Environment Act 2021 enshrined into law the requirement for the government in England to produce an Environmental Improvement Plan, as well as to report progress every year, have it scrutinised by the OEP and update it every five years.[11]

While this process has highlighted significant gaps between intention and action, as well as sometimes a lack of data to inform either, from my perspective, the business of choosing indicators, using them to shape key targets and then monitor progress towards them has developed significantly since 1990 (see **Figure 3**). We can only seek to interrogate, refine and communicate these indictors in pursuit of the targets that will most drive progress. ES

Julie Hill MBE is President of the IES. She is an inaugural Non-executive Board Member of England and Northern Ireland's Office for Environmental Protection and Chair of the Advisory Committee for Social Science for the Food Standards Agency. As well as several other non-executive roles, she was previously Executive Director of environmental thinktank Green Alliance. Julie has written and presented widely including the book *The Secret Life of Stuff*.[13] She was elected to the IES Council in 2016 and served as Vice Chair and Chair before being elected President in 2024.

REFERENCES

1. Green Alliance (1999) *Indicating Right: Environmental Performance Indicators for the Waste Management Sector*. https://issuu.com/greenallianceuk/docs/indicatingright1999 (Accessed: 20 May 2025).
2. Green Alliance (2002) *Creative Policy Packages for Waste: Lessons for the UK*. https://issuu.com/greenallianceuk/docs/creative_policy_packages_for_waste_overview (Accessed: 20 May 2025).
3. Sankey Diagrams (2013) *UK WRAP's vision of circular economy*. https://www.sankey-diagrams.com/uk-wraps-vision-of-circular-economy/ (Accessed: 16 June 2025).
4. United Nations Environment Programme (2011) *Decoupling: Natural Resource Use and Environmental Impacts from Economic Growth*. https://wedocs.unep.org/bitstream/handle/20.500.11822/9816/Decoupling_FReport_EN.pdf?sequence=1&isAllowed=y (Accessed: 20 May 2025).
5. BBC (2010) *Hans Rosling's 200 Countries, 200 Years, 4 Minutes – The Joy of Stats*. YouTube video, 4:47. https://youtu.be/jbkSRLYSojo?feature=shared (Accessed: 20 May 2025).
6. Rosling, H. (2019) *Factfulness Illustrated: Ten Reasons We're Wrong About the World – and Why Things Are Better than You Think*. Sceptre.
7. Ritchie, H. (2024) *Not the End of the World. How We Can Be the First Generation to Build a Sustainable Planet*. Chatto & Windus.
8. Van der Straaten, J. (1992) The Dutch national environmental policy plan: to choose or to lose. *Environmental Politics*, 1 (1), pp. 45–71. https://doi.org/10.1080/09644019208414008 (Accessed: 20 May 2025).
9. HM Government (1990) *This Common Inheritance*. London: HMSO.
10. Select Committee on Environmental Audit (1998) *Greening Government Report*. https://publications.parliament.uk/pa/cm199798/cmselect/cmenvaud/517/51707.htm#note56 (Accessed: 22 May 2025).
11. Office for Environmental Protection (2025) *Progress in Improving the Natural Environment in England 2023/2024*. https://assets.publishing.service.gov.uk/media/6788d121d0561c11b91d0490/Progress_in_Improving_the_natural_environment_in_England_2023-2024_web-accessible.pdf (Accessed: 20 May 2025).
12. Office for Environmental Protection (2024) *A Review of Implementation of the Water Framework Directive Regulations and River Basin Management Planning in England*. https://www.theoep.org.uk/sites/default/files/reports-files/A%20review%20of%20the%20implementation%20of%20River%20Basin%20Management%20Planning%20in%20England_Accessible.pdf (Accessed: 20 May 2025).
13. Hill, J. (2011) *The Secret Life of Stuff. A Manual for a New Material World*. Vintage.

INTERVIEW

Putting indicators into real-life context

Julie Hill talks to colleague **Rebecca Willis** about governance, telling stories and what makes an effective indicator.

JULIE HILL (JH): Could you start by giving us a quick overview of your career path?

REBECCA WILLIS (RW): I read social and political sciences at Cambridge, followed by an MA in Environment, Development and Policy at Sussex University. I worked at the European Parliament before becoming Head of Policy and then Director of Green Alliance, a leading environmental thinktank. I then spent a good few years working independently, alongside a series of advisory roles, including seven years as Vice-Chair of the Sustainable Development Commission. I am something of an unusual academic, having spent 20 years in the policy world before doing a PhD in my 40s and transferring to academia. That said, my interests have been consistent: primarily governance and policy on energy and climate change.

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JH: What is the focus of your current academic work?

RW: The relationship between citizens and the state – in essence, what people need from government and what government needs from people! Voting every five years in an election is not a good way for democracy to work. I believe people should be more engaged in decision-making particularly on climate choices, which is why I'm a strong advocate of tools such as citizen assemblies. We need more distributed conversations and more dialogue overall.

JH: The focus of this issue of *environmental SCIENTIST* is indicators: their purpose and usefulness. Do you have an example of an indicator that made a big impact on you?

RW: The big milestone for me was the Climate Change Act 2008, which institutionalised climate indicators. Because of the act, for the past 15 years, in all my work, I have been able to point to the legal targets and the fact that the UK needs to meet these targets if we are to meet our international commitments.

For me, indicators are a necessary but not sufficient condition of success. They are often too crude and there is always a danger that target-driven policy skews actions. We are at an interesting stage in how we account for progress on carbon reduction. We have production-based targets – we absolutely must measure that way – and while they are necessary they are not sufficient, in that we also need to measure consumption- and extraction-related emissions. A good example is Norway, a country that has done really well to decarbonise its economy; but this has been funded from oil revenue. This is in many ways great, but if we want to accurately measure Norway's contribution, the picture is more complicated.

I do think that if indicators and targets become central drivers of policy, we have lost something. But at the same time, the principle of indicators is that we need good measurement in order to manage. Overall, I'd counsel against getting too tied up in which indicator is the right one and look instead at the overall trajectory. Are we verifiably moving in the right direction?

JH: So a system-based viewpoint? Understanding whether we are influencing the right parts of the system?

RW: Yes. And it is also important to keep sight of the politics and rhetoric of change. For instance, the advertising industry has well-developed targets and standards for its own performance – the emissions involved when it produces and broadcasts an ad. But this ignores the question of what's being advertised. If we step back and think about the impact of the advertising sector, its main impact is in driving consumption, and that consumption might be good or bad. Recently, we worked with a citizens' panel to gauge people's views on whether advertising of high-carbon products and services should be managed to reflect their carbon impacts, and there was support for this idea.

JH: A lot of your work has been studying how politicians think about the environment, particularly climate change. I imagine that has made you feel both hope and despair! What have been the highlights of that work?

RW: I think it is important to treat politicians as people, with all the complex motivations and emotions that we all have. If we don't do that, we can't figure out how to work with them. It is easy to condemn politicians for not understanding or not caring – that does apply to some – but the best way of making progress is to think really hard about what makes people in their position tick and to appreciate the pressure they're under. With some of the current more negative positions on climate, the scepticism is not coming from failing to understand the science but from wider cultural and political pressures, including a misperception of public attitudes.

JH: But if the position has come from faulty analysis, how do we work with that?

RW: We have to keep going back to the fundamental evidence. For instance, on the proposed new coal mine in Cumbria, we had to keep repeating the evidence that we can't open a new coal mine and still stick to less than 2C of global warming, as well as keep pointing out the [UK's] legal commitment to the target. It is also important to understand the underlying social and economic drivers. It is about standing up for science and evidence while trying to understand why there is the erroneous idea that we have to make a trade-off between net zero and economic growth.

JH: What was the crucial factor that helped win the case against the Cumbria coal mine?

▲ **A bench overlooking St Bees beach on the Cumbrian coast, near the proposed coal mine site. © utamaria | Adobe Stock**

RW: In the end, the science won out. The courts ruled that emissions caused by burning the coal mined in Cumbria had to be taken into account in the decision, even if the coal was burned elsewhere. But it is important to ask why there was a lengthy court battle in the first place. In my view, there needs to be much better coordination between national and local policy on climate. The governance of climate and wider environmental issues has been very top-down: it has been a technocratic agenda, something done by people in Whitehall. Leaders should be clear about the direction of travel but relaxed about how local areas get there. It is important to devolve targets to a more local level, with appropriate attendant powers and responsibilities.

JH: Which indicators, or ways of presenting indicators, do you think make the most difference to politicians?

"Presenting politicians with indicators and targets is part of the evidence base, but we also need to find a way to their hearts and minds. "

RW: Presenting politicians with indicators and targets is part of the evidence base, but we also need to find a way to their hearts and minds. It is interesting what happens when the two approaches are combined. It can be brutally ineffective to reel off air pollution numbers and how many lives are modelled to be lost; but combined with a real story – such as that of the tragedy of Ella Adoo-Kissi-Debrah's death – it becomes immensely powerful. Ella's mother,

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Rosamund, could put a human face to the damage that air pollution causes, but she would not have been able to tell that story without the data behind it.

JH: You have recently been appointed an Expert Adviser to the Climate Change Committee (CCC). Do you feel that the CCC has been successful in the way it uses indicators? What are the lessons learnt?

RW: Climate targets, and the carbon budgets developed to help meet those targets, have been hugely influential. The CCC has been very effective at fulfilling its brief as laid down in legislation – not only providing advice on the budgets but supplying the pathways to meet them and then assessing government progress. All that is quite a technical task. However, as we move into looking for carbon savings from beyond the power and industrial sectors, savings that will entail changes at household and dietary level, we will need to have an even more rigorous focus on social co-benefits.

JH: Perhaps not many people know that the legislation requires the CCC to have regard of social factors?

RW: Perhaps not. The CCC's core expertise is in the carbon numbers, so it is an interesting question about how we combine those with indicators for health and social impacts; and how CCC then factors those into its advice to government. Part of my role is to help with that. There are some exciting developments. For the first time recently, CCC has used a model of types of households to assess the impacts of policy and used it as the basis of a citizens' panel. The panel attendees were asked what they thought about distribution of impacts – who should get grants, incentives, benefits – in a range of questions about equity. To have that discussion properly will need careful work with health organisations and other areas where there may be benefits beyond the carbon reduction. We need to show that carbon savings are associated with positive outcomes – better housing, for instance.

JH: Is that work similar to the work of the Just Transition Commission in Scotland? Does the Commission link to the CCC?

RW: Yes. And that piece of institutional architecture is very helpful in Scotland.

JH: Do you have any tips for IES members and our readers about how to present information in the most compelling ways?

RW: I would go back to the air pollution example: use a combination of stories and evidence. The story has to have an emotional element, something beyond being a case study. For example, did you hear the RSPB [Royal Society for the Protection of Birds] talking about stone curlews no longer being in decline?[1]

JH: Yes! That was so compelling.

RW: Exactly. A story about people and birds and indicators told so skilfully, it painted a picture that we both remember. ES

Rebecca Willis is Professor of Energy and Climate Governance at Lancaster University. She leads the Climate Citizens research group, which examines the role of public engagement in energy and climate governance. She is an expert adviser to the CCC and also advises Innovate UK's Net Zero Living initiative.

REFERENCES

1. Royal Society for the Protection of Birds (2025) *Stone-curlew numbers more than double thanks to 40 years of effort.* https://www.rspb.org.uk/whats-happening/news/stone-curlew-projects-anniversary (Accessed: 30 April 2025).

FEATURE

Pollution, impacts and progress in the use of chemicals

Magnus Løfstedt, Jeanne Vuaille, Chrystèle Tissier, Bastian Zeiger and **Maurizio Giardini** assess our progress towards their safe and sustainable use.

The ambition of the EU indicator framework for chemicals is to monitor the drivers and impacts of chemical pollution, measure the effectiveness of chemicals legislation, and follow the transition to the production and use of safe and sustainable chemicals. The current version of the framework, published in April 2024, is a first attempt to address this ambition.[1] It establishes a baseline from which the impact of ongoing chemicals policy actions will become apparent over time. The EU indicator framework was developed by the European Environment Agency (EEA) and the European Chemicals Agency (ECHA) in cooperation with the European Commission and other agencies.

FEATURE

THE EU INDICATOR FRAMEWORK FOR CHEMICALS

The indicator framework consists of an online dashboard and a synthesis report.[1] A total of 25 indicators are featured in the online dashboard. While some indicators were already available such as the one aimed at hazardous substances in marine organisms, new ones have been developed based on existing data streams.[2] A series of so-called signals was also produced to help understand trends in areas with limited information. These consist of qualitative assessments, research findings or quantitative data limited in terms of time and spatial coverage. Together, the indicators and signals provide insights that directly or indirectly monitor trends along the life cycle of chemicals (from manufacture to use and waste), their related emissions, impacts and regulatory actions, as well as developments in research and innovation.

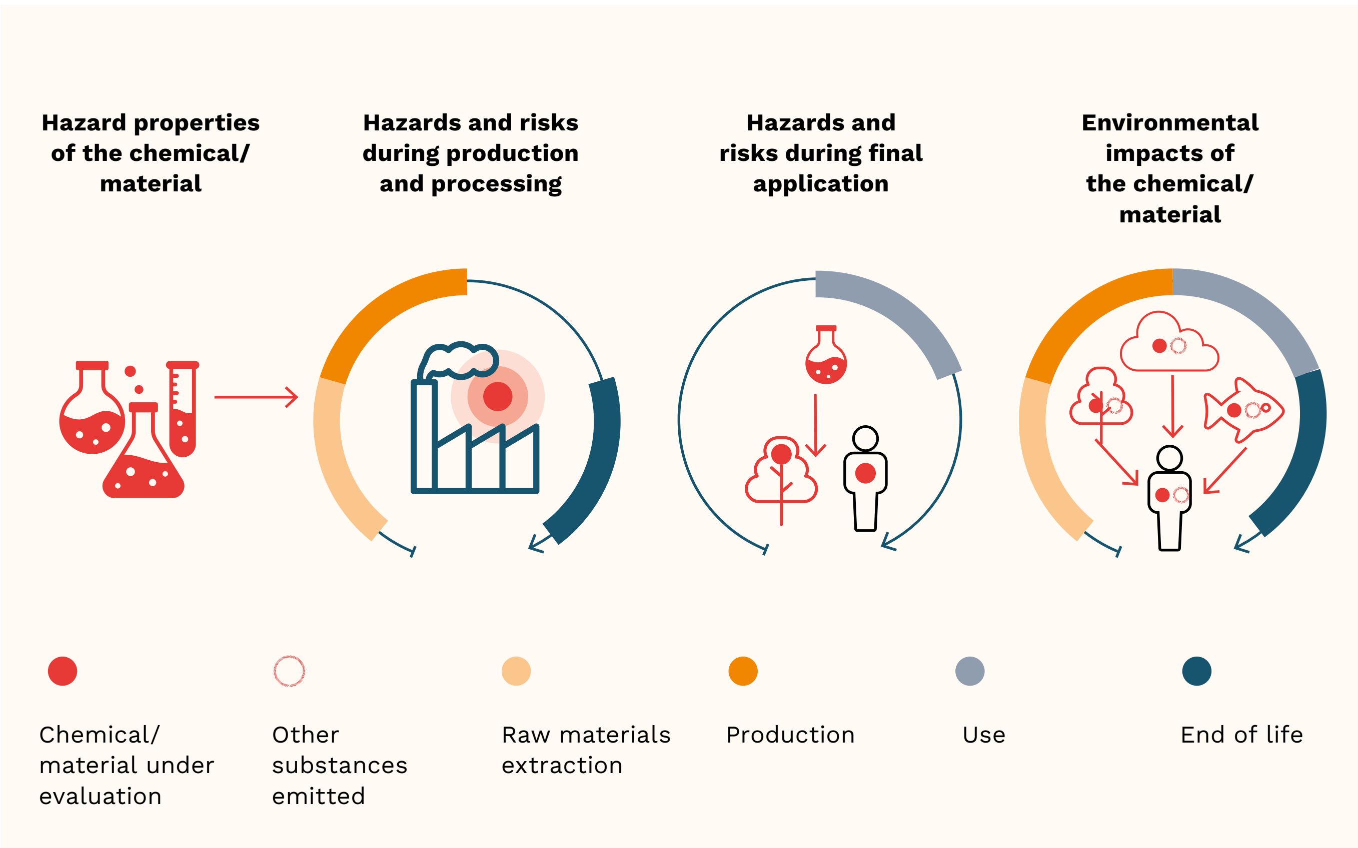
MONITORING PREVENTION AND IMPACTS

It is often either impossible or very costly to clean up pollution once it has occurred. Therefore, the focus is on preventing or minimising the use of harmful chemicals already in products and manufacturing processes to limit exposure to humans and the environment.

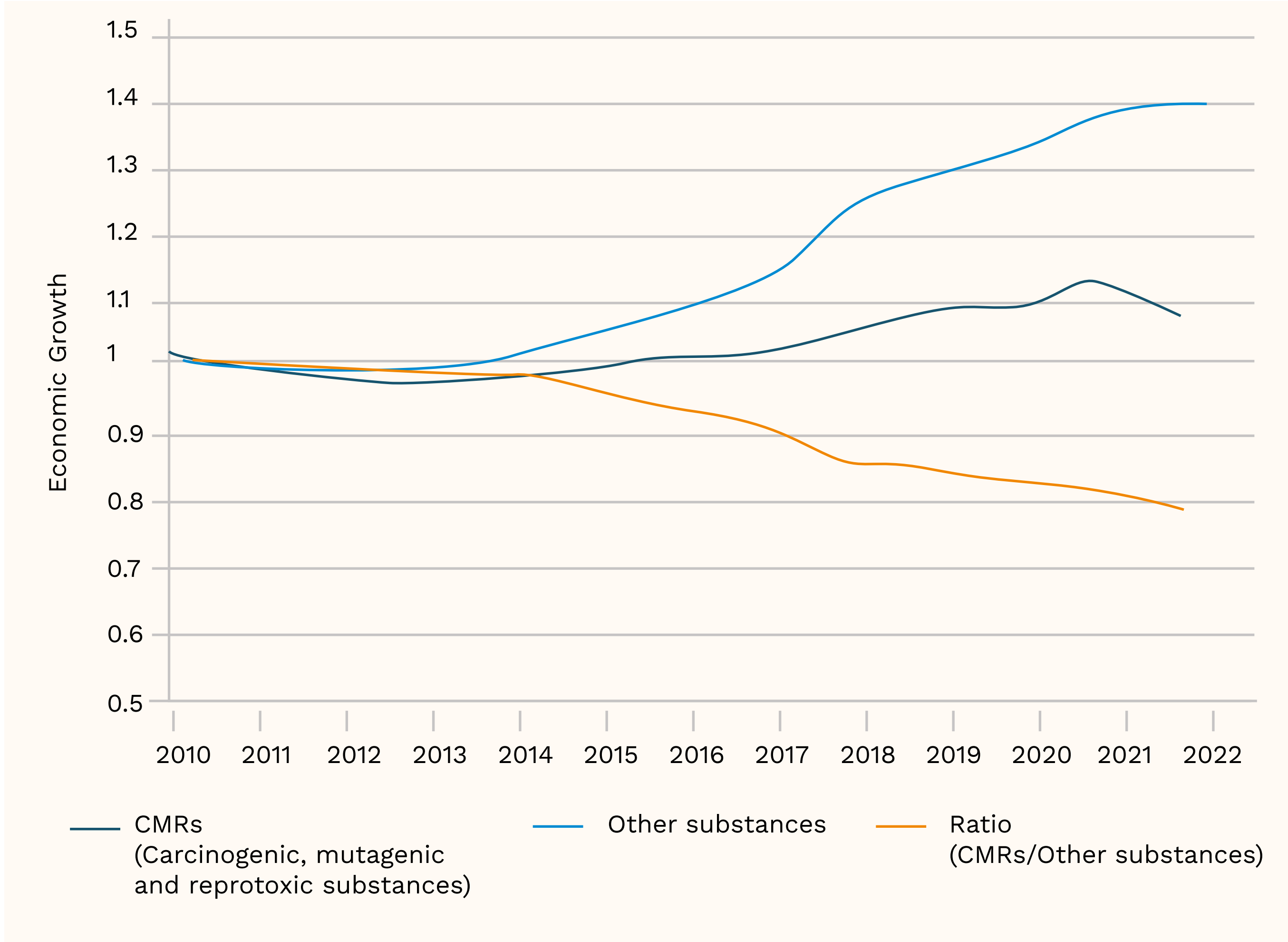
Monitoring chemicals downstream (e.g. in products, humans and the environment) can inform the effectiveness of upstream measures.

The recently established approach of safe and sustainable by design implies avoiding substances of concern for uses where safer alternatives are available, promoting the development of safe and sustainable chemicals and materials (i.e. ensuring clean production processes and technologies), and minimising products' environmental impacts during their use and disposal (see **Figure 1**). This requires assessment of the impacts for both human health and the environment at the design phase, as outlined in the European Commission's recommendation on the 'safe and sustainable by design framework' for chemicals and materials.[3]

Preventive approach. Seven indicators were gathered in the framework to assess the EU's status and progress in this upstream-preventive approach. One of them is a newly developed indicator by the ECHA, which shows the growth of the EU chemicals market for substances of different levels of concern (see **Figure 2**). The indicator is based on data from the registration



▲ **Figure 1. Safety and sustainability assessment of chemicals and materials. (Source: Adapted from Caldeira *et al.*, 2022[4])**



▲ **Figure 2. Growth of use volumes of REACH-registered substances of different levels of concern, relative to use volumes in 2010–22. (Source: European Chemicals Agency database[5])**

dossiers submitted under the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulation. It tracks how the use volumes of substances of varying concern have developed in the EU since 2010: in other words, it follows changes in volumes produced and imported, after subtracting volumes of chemicals exported from the EU or where there is no exposure to people and environment.

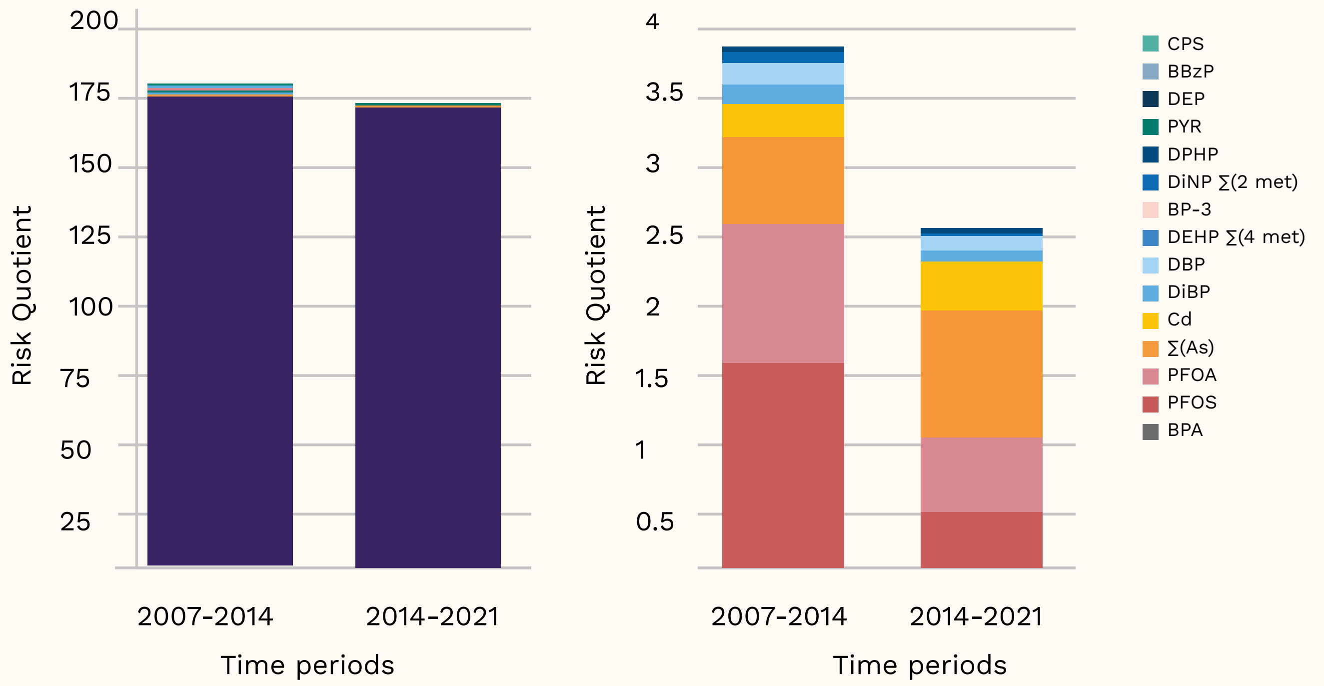
The indicator shows that the use of some of the most concerning substances, namely those that are carcinogenic, mutagenic and reprotoxic (CMR) in category 1, has grown over the past 10 years by 8 per cent. However, this use growth is 20 per cent slower than for all other substances. This shows that while, on the one hand, such substances continue to be used (typically in industrial applications under controlled conditions), on the other hand, the EU chemicals regulations targeting CMRs have to some extent controlled growth in their use.

Hard-to-replace chemicals. A total of 16 indicators and signals support the assessment of status and progress in minimising and controlling the risks for those chemicals that cannot currently be replaced with safer and more sustainable alternatives. Examples covered in the indicator framework include trends in the identification of new harmful substances and the consumption of ozone-depleting substances.

Chemicals pollution and impacts. Finally, a total of 16 indicators and 16 signals support the assessment of status and progress of the EU in eliminating and remediating chemical pollution. Success in preventing the use of harmful chemicals can be assessed by monitoring their occurrence in air, water and soil. Human biomonitoring is a powerful tool to understanding human exposure to chemicals: the measured internal concentrations in our bodies (usually in blood or urine) integrate all possible exposure sources. Environmental and human biomonitoring data can also shed light on ecosystems and human health risks associated with chemical pollution by comparing exposure and adverse effect levels.

One signal tracks the combined risk from exposure to 15 specific pollutants, based on human biomonitoring results from the European project HBM4EU, where a risk quotient above 1 indicates a potential risk (see **Figure 3**).[6] Seven of these pollutants drive the mixture risk: bisphenol A (BPA), the per-fluorinated chemicals PFOS and PFOA, arsenic, cadmium and two phthalate metabolites (monobutyl phthalate and monoisobutyl phthalate). BPA, in particular, is responsible for 98 per cent of the risk from the studied mixture. In addition, monitoring results from two time periods indicate a decrease in the overall human health risks in the EU from these specific substances. This indicates that the regulatory measures that have been implemented for some of these substances (e.g. PFOA, PFOS and BPA) have been successful in reducing human exposure, although not to a sufficiently low level.

This type of information can help authorities to decide where to prioritise regulatory interventions, and there are numerous ongoing regulatory actions for these substances in the EU. When updated



Notes: [a] CPS = chlorpyrifos; [b] BBzP = butylbenzyl phthalate; [c] DEP = diethyl phthalate; [d] PYR = pyrethroid insecticides; [e] DPHP = Di(2-propylheptyl) phthalate; [f] DiNP Σ(2met) = di-isononyl phthalate; [g] BP-3 = benzophenone 3; [h] DEHP Σ(4 met) = di(2-ethylhexyl) phthalate; [i] DBP = di-n-butyl phthalate; [j] DiBP = Di-iso-butyl phthalate; [k] Cd = cadmium; [l] Σ(As) = Arsenic, inorganic; [m] PFOA = per-fluorooctanoic acid; [n] PFOS = per-fluorooctanesulfonic acid; [o] BPA = bisphenol A. Human biomonitoring was undertaken for the detection of biomarkers of these 15 substances.

▲ **Figure 3. Risk of a mixture of 15 substances prioritised for human biomonitoring in the European population in the periods 2007–14 and 2014–21. Bisphenol A has been excluded from the graph on the right to show the contribution from the other monitored substances. (Source: Information Platform for Chemical Monitoring, no date-a, no date-b[7,8])**

with new human biomonitoring data, the indicator will help to track the effect of these regulatory interventions to reduce exposure. The availability of data regarding use and exposure of currently used substances is an important limitation that ongoing research is attempting to overcome. This will ultimately require the development of new environmental monitoring frameworks and innovative techniques to ensure the most problematic substances are covered. The effort to coordinate and advance environmental and human (bio)monitoring to provide evidence for chemical policy-making is continuing under the Partnership for the Assessment of Risks from Chemicals.[9]

CONCLUSION AND FUTURE PERSPECTIVES

Conclusions from the synthesis report. A number of conclusions can be drawn from this work. Firstly, the transition towards safer and more sustainable chemicals is progressing in some areas while in others it is just getting started, such as research and innovation for safe and sustainable by design chemicals and materials. Secondly, action by authorities and industry has supported minimising and controlling the risks from several groups of hazardous chemicals – for example, by increasing knowledge of hazardous properties, supporting risk management actions and frequent compliance checks of chemicals placed on the EU market. However, further effort is needed to close remaining knowledge gaps for a number of substances and to address a high level of non-compliance for specific chemicals under REACH restrictions.

When it comes to chemical pollution, available data suggest that there is little evidence of progress towards eliminating substances of concern from waste and secondary materials, and data at the EU level on this topic are scarce. Emissions of certain chemicals to water and air have fallen following specific EU regulatory (e.g. on industrial emissions) and international actions, but further measures are needed to reach levels that are not harmful for human health and the environment.

The scope of the indicator framework is wide, covering industrial chemicals, pesticides, heavy metals, chemicals in consumer products like cosmetics and toys, and pharmaceuticals. These main conclusions were drawn while fully

FEATURE

acknowledging the limitations in the data at hand. Numerous monitored chemicals are substances no longer intentionally in production or used in specific settings (e.g. legacy pesticides) as they have been or are being phased out, and only specific hazard categories are covered. Therefore, while individual indicators may not be sufficient to directly assess the drivers and impacts of chemical pollution and their regulation, the framework as a whole supports that overarching assessment. Key data and knowledge gaps were identified in the report, such as monitoring data covering currently used substances compared to legacy ones and, specifically, in waste streams. This will help to guide further development of new indicators.

Future perspectives - improving early warning on emerging chemicals risks. Based on past experiences it has become clear that authorities often react too late to new and emerging risks and that use of the precautionary principle in many cases could have reduced damage to ecosystems, impacts to human health and remediation costs.[10]

An early warning system is a systematic approach to identifying signals of emerging chemicals risks, which could help to reduce the time taken before regulatory actions are initiated, thereby reducing pollution and exposure at an earlier stage. Such a system would need to be based on a combination of multiple types of information, which could include the use of indicators. In particular, indicators for environmental or human (bio)monitoring could help to track exposure over time to new or well-known harmful substances, where increased exposure could indicate emerging evidence of changing use patterns of a substance or new substances entering the market to substitute for ones that are being phased out.

Monitoring data provide some of the strongest evidence we have on real-life exposure to chemicals and on their potential impacts to ecosystems and health. Indicators and signals have been developed for both human exposure and occurrence in the environment (see **Figure 3**). However, there are still limitations in data availability over time and space, which limit the potential of such indicators. Future developments could lead to new opportunities for the indicator framework, extending beyond its original purposes. The framework is therefore expected to be updated and developed as new data and knowledge become available. It is a living product that will eventually capture a greater proportion of currently used substances and trends in ecosystem and human exposure. **ES**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Magnus Løfstedt is an Expert in Environmental and Human Health Effects of Chemicals at the EEA. He is a biologist by training, and prior to joining the EEA he worked for 15 years at the Danish Environmental Protection Agency on a variety of chemicals-related legislation.

Dr Jeanne Vuaille is an Expert in Environmental and Health Data Analysis at the EEA. An environmental engineer by training, she conducted her PhD studies at the University of Copenhagen. Her research focused on pesticide and pharmaceuticals pollution in agricultural settings.

Chrystèle Tissier is a Regulatory Officer at the ECHA and has a background in ecotoxicology and ecology. She has worked in chemicals legislation both at national level in France and at European level, with a particular focus on substances of concern and risk management.

Bastian Zeiger is a Regulatory Officer at the ECHA and has a background in environmental sciences and resource management. In the past, he has worked on industrial pollution and control at the European level and more recently on chemical risk management at the ECHA.

Maurizio Giardini is a Governance Officer at the ECHA and has a background in engineering, project management and consulting. He facilitated performance management projects in the private and public sectors, including development of reports and indicators, involving multiple stakeholders.

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REFERENCES

1. European Environment Agency and European Chemicals Agency (2024) *EU Indicator Framework for Chemicals.* EEA Report 02/2024. https://www.eea.europa.eu/publications/eu-indicator-framework-for-chemicals (Accessed: 29 April 2025).
2. European Environment Agency (no date) *Hazardous substances in marine organisms in European seas (Indicator).* https://www.eea.europa.eu/en/european-zero-pollution-dashboards/indicators/hazardous-substances-in-marine-organisms-in-european-seas (Accessed: 10 May 2025).
3. Commission Recommendation (EU) 2022/2510 of 8 December 2022 establishing a European assessment framework for 'safe and sustainable by design' chemicals and materials. https://eur-lex.europa.eu/eli/reco/2022/2510/oj (Accessed: 29 April 2025).
4. Caldeira, C., Farcal, R., Garmendia Aguirre, I. *et al.* (2022) *Safe and Sustainable by Design Chemicals and Materials. Framework for the Definition of Criteria and Evaluation Procedure for Chemicals and Materials.* JRC Technical Report. https://publications.jrc.ec.europa.eu/repository/handle/JRC128591 (Accessed: 29 April 2025).
5. European Chemicals Agency Chemicals Database (no date) Home page. https://chem.echa.europa.eu/ (Accessed: 11 May 2025).
6. HBM4EU (2017) *HBM4EU – Science and policy for a healthy future.* https://www.hbm4eu.eu/about-us/ (Accessed: 29 April 2025).
7. Information Platform for Chemical Monitoring (no date-a) *HBM4EU Aligned Studies – aggregated HBM data HBM4EU aligned studies.* https://ipchem.jrc.ec.europa.eu/#showmetadata/HBM4EUALIGNEDSTUDIES (Accessed: 29 April 2025).
8. Information Platform for Chemical Monitoring (no date-b) HBM4EU-aggregated – *HBM4EU aggregated workbook by VITO.* https://ipchem.jrc.ec.europa.eu/#showmetadata/HBM4EUAGGREGATED (Accessed: 29 April 2025).
9. Partnership for the Assessment of Risks from Chemicals (no date) Home page. https://www.eu-parc.eu/ (Accessed: 29 April 2025).
10. European Environment Agency (2013) *Late Lessons from Early Warnings: Science, Precaution, Innovation.* Summary. https://doi.org/10.2800/70069 (Accessed: 29 April 2025).

Cutting unsustainable consumption

Emily Carr explains why setting an ambitious target should be the powerful first step to bring UK resource use within planetary boundaries.

Global resource extraction has been left to grow largely unchecked, with the extraction of metals, minerals, fuels and bioresources nearly quadrupling between 1970 and 2024. According to the United Nations (UN), this is the cause of 90 per cent of biodiversity loss, over 55 per cent of all global greenhouse gas emissions and 40 per cent of health-related impacts from particulate air pollution.[1]

Tracking trends is important but alone it is not enough to drive more action to reduce consumption to sustainable levels; meaningful intervention is required. Global action to address the climate crisis has been guided by Paris Agreement commitments in recent years, and in the UK legally binding targets and independent advice have been enshrined through the Climate Change Act 2008 and Climate Change Committee. But no equivalent framework exists for resource use, despite its implications for the ability of societies to thrive in the future.

There is some recognition of the need to do something about this, with some countries across Europe setting 'material footprint' targets. Finland, for instance, aims to reduce its material footprint to below 2015 levels by 2035, and Austria is targeting a reduction target of less than 7 tonnes per person per year by 2050.[2,3] The Netherlands has set an ambitious goal to halve its footprint by 2030, whereas Spain is aiming for a more moderate 30 per cent reduction by the same year.[4,5] However, none of these targets are statutory, which means that no country has yet set a legally binding target to cut its resource consumption.

ANALYSIS

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OUT OF SIGHT, OUT OF MIND

Of course, not all countries bear the same responsibility for unsustainable consumption. High-income nations use, on average, six times more of the world's resources per head than low-income countries.[1] They benefit from 'unequal exchange', where raw materials, energy and labour flow from poorer to richer nations at low prices that fail to reflect the harm caused. Worryingly, this flow is growing in the UK: in 1997, 60 per cent of material needed to meet demand came from abroad, but by 2018 this had risen to 73 per cent.[6]

This deepens global inequalities, pushing the environmental and social costs of our consumption on to other countries. The devastating impacts of this include deforestation, water scarcity and species extinction. For instance, mining is the fourth largest driver of deforestation globally, with tropical forests particularly affected. A quarter of global deforestation related to mining is in Indonesia, and a further 12 per cent occurs in Brazil.[7] It is time the UK showed greater leadership and moved away from the 'out of sight, out of mind' attitude towards our offshored impacts.

A TARGET SHOULD BE THE GUIDING LIGHT

If they balance practical considerations and scientific thresholds, national governments and other stakeholders can unite behind a target and commit to actions to drive progress – as seen with the remedial actions taken on the climate agenda. A consumption reduction target could act as a guiding light, leading government initiatives on creating a more sustainable economy.

Government advisers have made the importance of target setting clear. The Office for Environmental Protection, for example, says that statutory targets on resource use are 'extremely significant' as they 'crystallise and lay bare the level of government ambition for the environment, at a time when so much ambition is needed, and with change required at pace in so many areas'.[8] This was echoed by the HM Treasury-commissioned Dasgupta Review on the economics of biodiversity in 2021, which argued for greater clarity in how resource use is measured, based on the science, to build a sustainable economy in which resource demand does not outpace supply.[9]

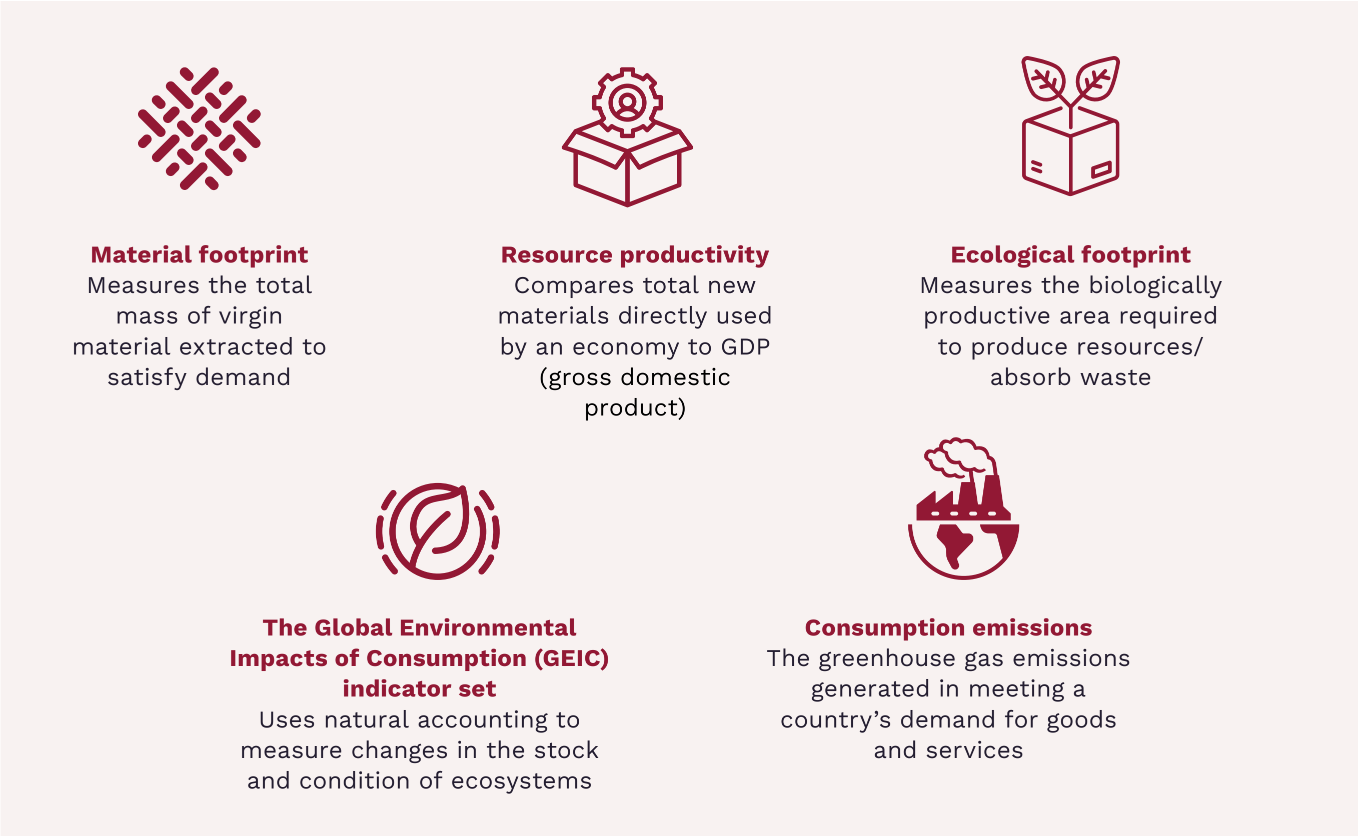
The major question to ask of any potential target is whether it can drive the action needed to significantly reduce the environmental impacts of resource consumption. For a target to be an effective driver, its metric must be primarily sensitive to the actions it is meant to incentivise. Since the goal is to reduce material overconsumption and its associated impacts, progress should therefore only be achievable through actual reductions in material use.

To be comprehensive, it must be an economy-wide metric, covering all materials and sectors. However, because different materials have different impacts, data must also be sufficiently granular and capable of being broken down by sector or material type to enable the setting of specific sub-targets that can support the headline goal. Crucially, this must be reliable and accurate enough to know whether and when sustainable limits are exceeded.

METRICS UNDERPINNING A TARGET

There are five metrics on which a target could be based.

1. Material footprint measures the total mass of virgin material extracted to satisfy demand, based either on domestic material consumption, which does not fully account for all the materials used in supply chains, or raw material consumption, which does. (Domestic material consumption, which is



▲ **Figure 1. Illustration of metrics underpinning a target.**

more commonly used, is production-based and shows the total quantity of materials directly used within an economic system. It is calculated as the sum of domestic extraction and imports minus exports. Raw material consumption shows the total amount of domestic and foreign extraction of materials needed along all supply chains to produce the final products consumed in a country.)

An appropriate UK target would be to at least halve its material footprint. At 16.5 tonnes per person, the UK's material use is currently more than twice the UN's estimated sustainable range of 3–8 tonnes per person per year; many different studies have reached similar figures for sustainable levels per person for global consumption of materials.[10-15] The value of this type of target is that it is solely sensitive to reductions in material consumption and covers all materials. Its downside is that it relies on complex estimations that convert the monetary values of trade flows into raw-material equivalents, making accurate calculations time-intensive and complex, and potentially requiring further investment to enhance the metric's reliability and practicality.

2. Resource productivity builds the material footprint into an economic ratio, comparing the total new materials directly used by an economy to an economic indicator – typically, gross domestic product (GDP). This means it is sensitive both to increasing economic growth and reducing material consumption. While it shares the whole-economy, granularity and reliability strengths with the material footprint, as a tool it fails in setting sustainable resource use targets. Because it is a ratio, improvements can be achieved simply by increasing GDP, making it impossible to set a resource productivity target that guarantees sustainable resource use. Nevertheless, the previous UK Government set a non-binding target to double resource productivity by 2050.

3. Ecological footprint as a metric moves away from the mass-based approach and measures the biologically productive area (expressed in global hectares) required to produce resources and absorb waste. It fully accounts for biomass resources and greenhouse gas emissions, but only considers non-renewable resources like minerals and metals, insofar as they require land or lead to

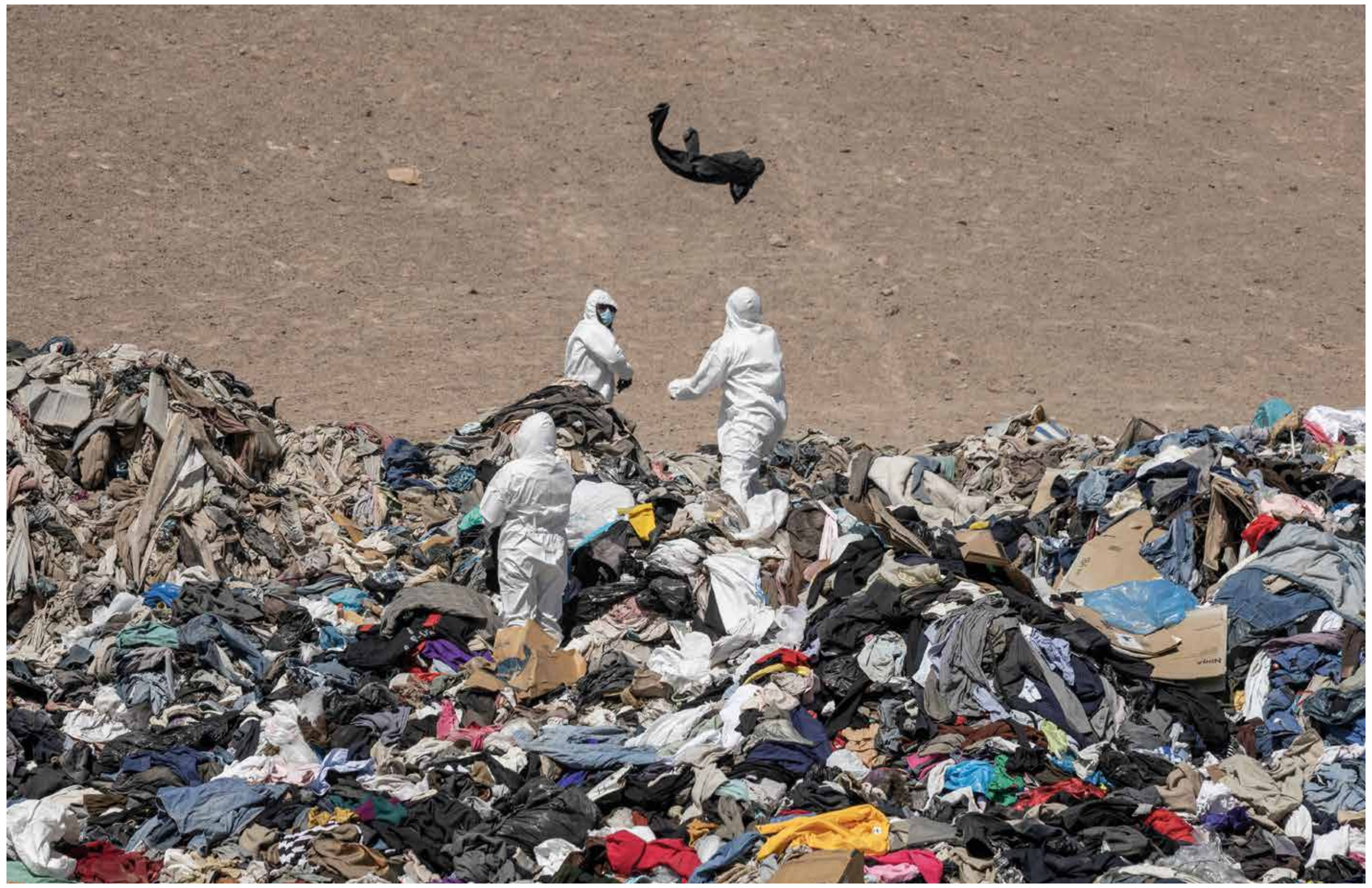
emissions. Bringing this footprint within planetary boundaries means halving it, since the UK uses 3.6 global hectares per person, more than twice the sustainable range of 1.6–1.7 global hectares.[16,17]

But this metric has some key limitations. Critics have questioned the estimates used to calculate average forest sequestration, which can significantly affect the assessment of footprint size.[18] Since the metric does not fully account for non-renewable resources, it also overlooks resource depletion, with other crucial omissions including the impact of inherently unsustainable activities, like the release of heavy metals, radioactive materials and persistent synthetic compounds, and the impacts of ecological degradation.[19]

4. The Global Environmental Impacts of Consumption (GEIC) indicator set similarly uses natural accounting to measure changes in the stock and condition of ecosystems, evaluating biodiversity loss, water impacts, deforestation and other consumption consequences. Under this, improvements result from reducing consumption and increasing production sustainability.

But, since it primarily tracks trends, it is not wholly suitable on its own for target setting. However, absolute targets such as zero deforestation or relative targets such as limiting species loss linked to UK consumption are feasible for many of the individual indicators within the set. The main strength of the GEIC is its ability to measure impact rather than just mass with highly detailed data down to the commodity level. Although it recently achieved official government statistic status in the UK, so far it only applies to agricultural commodities, with further work needed to expand its scope to other products.

5. Consumption emissions, lastly, refer to the greenhouse gas emissions generated in meeting a country's demand for goods and services, including those from imported goods but excluding exports. UK consumption emissions are falling more slowly than its territorial emissions (i.e. those that occur within its borders), so a long-term sustainable consumption emissions target should be aligned with the UK's territorial emissions target to reach net zero.[20] The main benefit of this is that the data are both comprehensive and granular, covering all goods



▲ **Textile waste in the Atacama Desert, Chile. © Macrofolio | Adobe Stock**

and services, with a breakdown extending to over 500 sectors. However, the metric is less specifically focused on material consumption than others. Alternative methods to reduce emissions, such as decarbonising production processes, mean there are other routes to meeting a consumption emissions target without necessarily reducing overall consumption.

NEXT STEPS FOR THE UK GOVERNMENT

From this assessment, the material footprint metric would seem to be the most useful for monitoring overall reductions in resource use and setting an impactful target. However, it is relatively blunt and cannot account for the differing impacts of materials, which vary by type, location and production process. To ensure the metric drives the best outcomes and avoids perverse incentives, complementary measures are necessary. For instance, combining the material footprint with impact-based metrics, such as the GEIC indicator set, would be a good solution.

In November 2024, the Circular Economy Taskforce was launched – a group of experts from industry, academia and civil society charged with helping the government to codesign a strategy for an economy where we 'use our resources in the best way and to the best possible effect'.[21] This is the ideal opportunity to introduce ambitious resource use targets.

Setting a headline material footprint target to at least halve resource use across the whole supply chain, underpinned by specific targets for high-impact sectors and commodities, and complemented by the impact-based GEIC indicator set are the vital next steps for the UK. This move, beyond simple tracking and monitoring, is long overdue and has the potential to drive real action towards reducing unsustainable consumption. ES

Emily Carr is a policy adviser in the resources theme at Green Alliance, an independent thinktank and charity focused on ambitious leadership for the environment. Emily works across range of resource policy topics and has a particular interest in circular business models and innovative approaches to consumption reduction.
✉ **ecarr@green-alliance.org.uk**

REFERENCES

1. United Nations Environment Programme International Resource Panel (2024) *Global Resources Outlook 2024 – Bend the Trend: Pathways to a Liveable Planet as Resource Use Spikes.* https://wedocs.unep.org/handle/20.500.11822/44901 (Accessed: 26 April 2025).
2. Ministry of the Environment and Ministry of Employment and the Economy (2021) *Government Resolution on the Strategic Programme for Circular Economy.* Resolution, 8 April. https://ym.fi/en/strategic-programme-to-promote-a-circular-economy (Accessed: 26 April 2025).
3. Federal Ministry Republic of Austria Climate Action, Environment, Energy, Mobility, Innovation and Technology (2022) *Austria on the Path to a Sustainable and Circular Society. The Austrian Circular Economy Strategy.* https://circulareconomy.europa.eu/platform/sites/default/files/2023-10/Austrian_CES.pdf (Accessed: 26 April 2025).
4. The Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs, also on behalf of the Ministry of Foreign Affairs and the Ministry of the Interior and Kingdom Relations (2016) *A Circular Economy in the Netherlands by 2050.* https://circulareconomy.europa.eu/platform/sites/default/files/17037circulaireeconomie_en.pdf (Accessed: 26 April 2025).
5. Ministry for Ecological Transition and the Demographic Challenge (2020) *España Circular 2030. Circular Economy Spanish Strategy.* Executive summary. https://www.miteco.gob.es/content/dam/miteco/es/calidad-y-evaluacion-ambiental/temas/economia-circular/200714eeec_resumenejecutivo_en_tcm30-510578.pdf (Accessed: 26 April 2025).
6. Office for National Statistics (2021) *Material footprint in the UK: 2018.* https://www.ons.gov.uk/releases/materialfootprintintheuk2018 (Accessed: 26 April 2025).
7. Kramer, M., Kind-Rieper, T., Munayer, R. *et al.* (2023) *Extracted Forests: Unearthing the Role of Mining-related Deforestation as a Driver of Global Deforestation.* WWF Germany. https://wwfint.awsassets.panda.org/downloads/wwf_studie_extracted_forests_1_1.pdf (Accessed: 26 April 2025).
8. Office for Environmental Protection (2022) *Advice on Environmental Targets.* Letter to The Rt Hon George Eustice MP, Secretary of State for Environment, Food and Rural Affairs, and Rebecca Pow MP, Minister for Nature Recovery and the Domestic Environment, 27 June. https://www.theoep.org.uk/sites/default/files/reports-files/Advice%20on%20environmental%20targets%20-%20Advice%20letter%20%26%20Annex_CLEAN%20%281%29.pdf (Accessed: 26 April 2025).
9. Dasgupta, P. (2021) *The Economics of Biodiversity: The Dasgupta Review.* PU3069. HM Treasury. https://assets.publishing.service.gov.uk/media/602e92b2e90e07660f807b47/The_Economics_of_Biodiversity_The_Dasgupta_Review_Full_Report.pdf (Accessed: 26 April 2025).
10. Office for National Statistics (2024) *Material flows.* Dataset. https://www.ons.gov.uk/economy/environmentalaccounts/datasets/ukenvironmentalaccountsmaterialflowsaccountunitedkingdom (Accessed: 26 April 2025).
11. Dittrich, M., Giljum, S., Lutter, S. and Polzin, C. (2012) *Green Economies Around the World? Implications of Resource Use for Development and the Environment.* https://www.boell.de/sites/default/files/assets/boell.de/images/download_de/201207_green_economies_around_the_world.pdf (Accessed: 26 April 2025).
12. United Nations Environment Programme International Resource Panel (2014) *Managing and Conserving the Natural Resource Base for Sustained Economic and Social Development.* https://www.resourcepanel.org/file/244/download?token=OHRPH1MH (Accessed: 26 April 2025).
13. Bringezu, S. (2015) Possible target corridor for sustainable use of global material resources. *Resources*, 4 (1), pp. 25–54. https://doi.org/10.3390/resources4010025 (Accessed: 26 April 2025).
14. O'Neill, D.W., Fanning, A.L., Lamb, W.F. and Steinberger, J.K. (2018) A good life for all within planetary boundaries. *Nature Sustainability*, 1, pp. 88–95. doi:10.1038/s41893-018-0021-4.
15. World Wide Fund for Nature (2021) *Thriving Within Planetary Means. How to Reduce the UK's Production and Consumption Footprint by 2030.* wwf.org.uk/sites/default/files/2021-07/Summary_thriving_within_ our_planetary_means_FINAL.pdf (Accessed: 26 April 2025).
16. Global Footprint Network (no date) *Free public data set.* www.footprintnetwork.org/licenses/public-data-package-free/ (Accessed: 26 April 2025).
17. Global Footprint Network (no date) *Glossary*. https://www.footprintnetwork.org/resources/glossary/ (Accessed: 26 April 2025).
18. Mancini, M.S., Galli, A., Niccolucci, V. *et al.* (2016) Ecological footprint: refining the carbon footprint calculation. *Ecological Indicators*, 61 (Part 2), pp. 390–403. https://doi.org/10.1016/j.ecolind.2015.09.040 (Accessed: 26 April 2025).
19. Global Footprint Network (2020) *Ecological Footprint Accounting: Limitations and Criticism.* Version 1.2. www.footprintnetwork.org/content/uploads/2020/12/Footprint-Limitations-and-Criticism.pdf (Accessed: 26 April 2025).
20. Office for National Statistics (2024) *Measuring UK greenhouse gas emissions.* www.ons.gov.uk/economy/environmentalaccounts/methodologies/measuringukgreenhousegasemissions (Accessed: 26 April 2025).
21. HM Government (no date) *Circular Economy Taskforce.* www.gov.uk/government/groups/circular-economy-taskforce (Accessed: 26 April 2025).

CASE STUDY

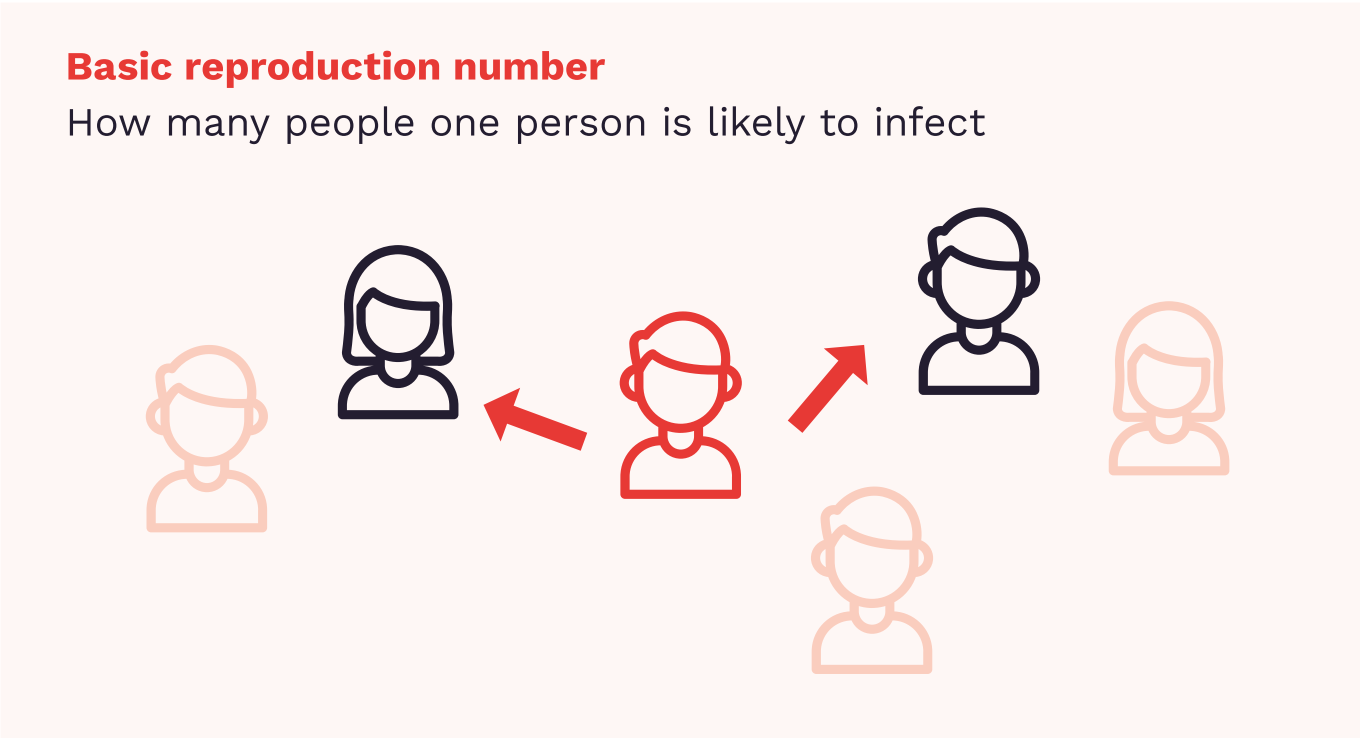
Starting from scratch: developing new climate change metrics

Freya Roberts, **Lucy Hubble-Rose** and **Kris De Meyer** reveal the communications expertise and psychological insights behind a new set of climate change metrics.

▲ **The UK Minister for Energy Security and Net Zero with other delegates at COP29, in 2024.**

A metric is defined as a standard for measuring something quantifiable. In the field of climate change, that something might be greenhouse gas emissions, temperature extremes or the reflectivity of the Earth's surface. But metrics do not just exist to help humans observe the changing climate. They can also be used to help make policy decisions that can limit the human activities causing climate change. When used in this way, metrics are important communication tools, so it makes sense to pay special attention to how they are designed and built.

CASE STUDY



▲ **Figure 1. An illustration of the reproduction number, showing how infection spreads.**

That is what one team at University College London (UCL) did, starting in the summer of 2021. The UCL Climate Action Unit (CAU) is a group of experts from across the fields of neuroscience, psychology, science communication and facilitation. The aim of the CAU's work is to accelerate the uptake of climate action across society. It does this by bringing together professionals from different sectors to collaborate and co-produce solutions to systems-change challenges, and by supporting professionals from one sector to understand the needs of end users in others. In short, the CAU applies insights from academia and research to real-world contexts.

By interrogating the traits of metrics that make them function well as a communications tool, and by working closely with design experts, the team has tailor-made a new set of climate metrics for policy-makers (and policy advisers).

PROJECT IMPETUS

The decision to dive into the world of climate metrics was sparked by a request for help. The CAU was enlisted to facilitate a workshop of scientists, civil servants, data experts and communications professionals. The idea behind the workshop came from the World Wide Fund for Nature (WWF) and the philanthropic funder Quadrature Climate Foundation, which wanted to explore what lessons could be learned from the way risk had been communicated during the Covid-19 pandemic.

The CAU's mission was to interrogate how the public had engaged with metrics like the reproduction (R) number: what made it such an effective way to talk about the risks of Covid-19? Climate change, the funders felt, lacked an equally well-recognised indicator of risk. There was no single metric that dominated the public's awareness so well, no tool that could as easily explain the impetus for political actions. This was the problem that needed a fix.

WHAT THE R NUMBER TAUGHT US

By analysing the contributions of the workshop experts, the CAU identified several traits within a metric that improve how well it functions as a communication tool. For example, it helps when a metric is closely linked to the dynamics of the system it refers to. The R number represented – in an almost mechanical way – how the coronavirus spread (see **Figure 1**). Could a climate metric simulate that too?

Another lesson was that when it comes to metrics, small numbers are easier to digest.

"Our brains cannot deal very well with big numbers: we find them difficult to remember and hard to conceptualise."

Our brains cannot deal very well with big numbers: we find them difficult to remember and hard to conceptualise. That might come as a surprise, given the conventional practice in the climate world of using big numbers to convey the worrying scale of the risk.

A third important trait that was uncovered was the importance of having a clear, objective threshold. The R number had a clear boundary between good and bad: below 1, good; above 1, bad (see **Figure 2**). No individual needed to decide what the acceptable threshold should be, as it was not based on personal opinion. That is quite different from climate change's 1.5C warming target, which is a politically agreed threshold. For many, 1.5C is too much given the consequences this will have. For the most vulnerable regions in the world, the impact of even a small amount of warming is intolerable.

The fourth reflection on what had worked well about the R number was that it showed the situation in that moment. It offered a real-time measure, one that could fluctuate over relatively short timescales. This responsiveness and focus on the present moment ultimately made it useful for policy-makers by enabling them to justify difficult decisions, such as whether to enforce or relax lockdown measures.

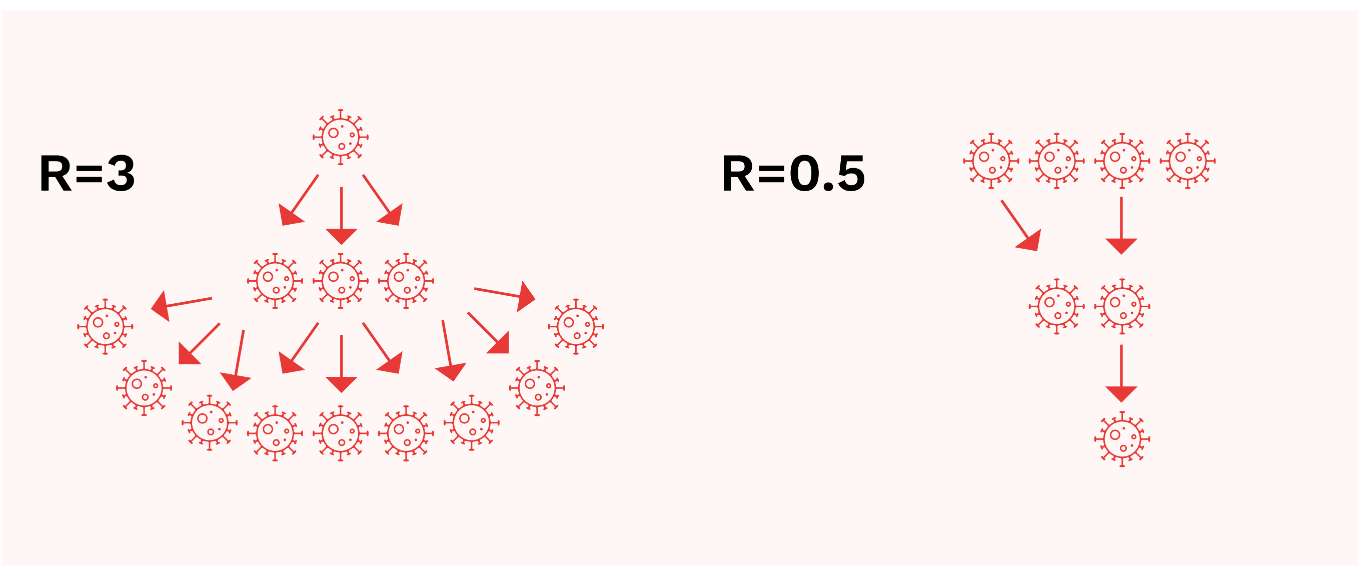
HOW NUMBERS ACQUIRE MEANING

Beyond these more visible traits of a metric, the CAU team also explored the ways in which people become familiar with metrics and start to internalise their meanings.

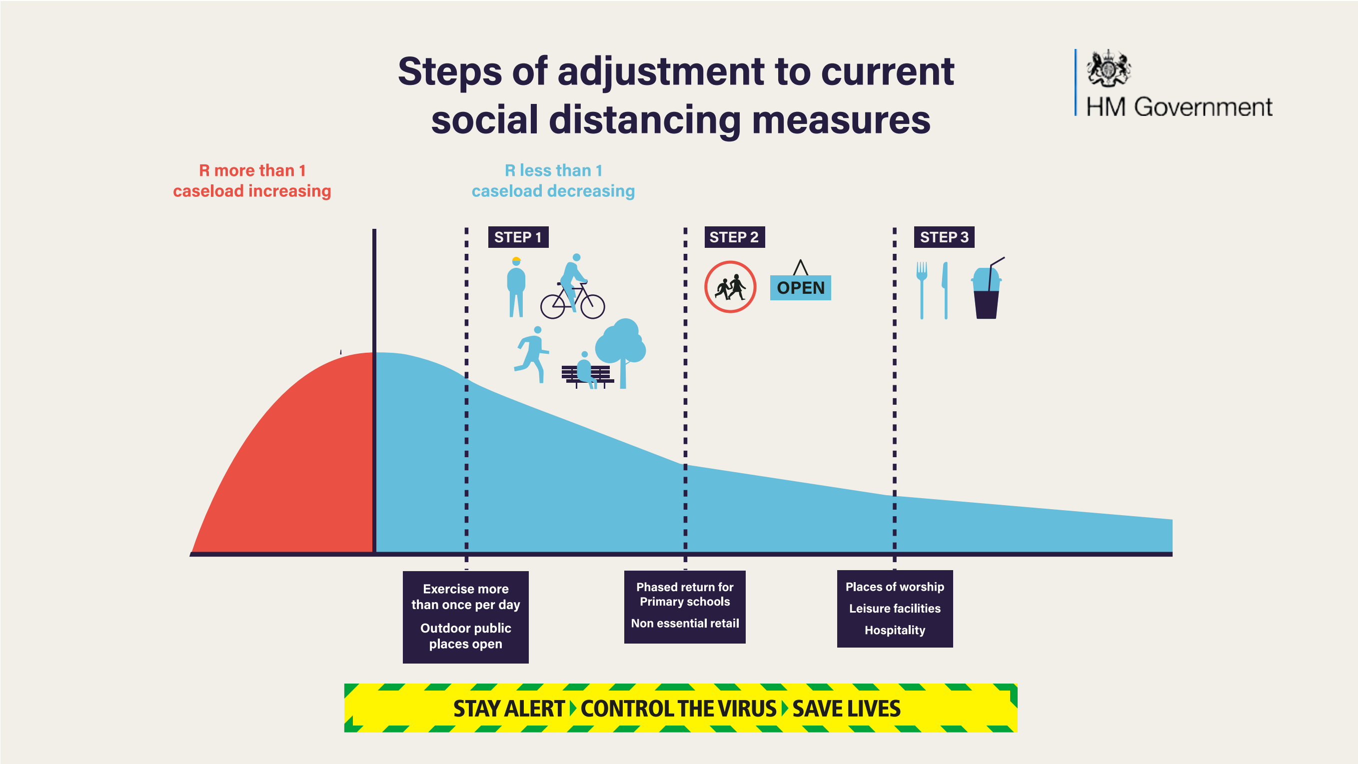
It is worth acknowledging that numbers do not have meaning in and of themselves. Numbers are relatively abstract: they need to be put into context to tell us anything useful. Even if a number is presented with a unit of measurement, it is still difficult for the reader to know whether it is significant or how it affects them. This is important to bear in mind when using numbers to communicate risks associated with climate change, because it is through providing supporting structures that our brains can start to internalise an abstract concept.

During the pandemic, the concept of the R number grew to have meaning over time. It started to stick in people's minds as it was explained repeatedly in story form. That storytelling was often supported with the use of visuals and graphics, particularly by the media and in government briefings.

These stories and visuals helped people link the scientific concept of a virus's replication rate to the more imaginable idea of going to a party with



▲ **Figure 2. A visual showing how the reproduction number correlates to the growth or decline in the number of infected individuals in a population.**



▲ **Figure 3. A UK Government illustration showing the steps of adjustment to social distancing measures. (Source: UK Government, 2020[2])**

their family and friends and unknowingly spreading the virus to two or three others in the room.

THE PURPOSE OF EXISTING CLIMATE METRICS

When this project began, many climate metrics already existed and were being used by the media. However, few (if any) had the same level of fame as the R number had during the pandemic.

As part of the wider project, the CAU also dedicated time to assessing the purpose of existing climate metrics. For example, they observed that climate metrics were often used as headline figures. When the amount of carbon dioxide in the atmosphere first exceeded 400 parts per million, for instance, that number became a media headline.[1] This is an example of metrics being used as a warning (of sorts). The team also found many examples of climate metrics being used to prove that climate change is real and is happening. For example, the level of warming since the pre-industrial era conjures a clear visual link for many between rising carbon emissions and the global temperature increase.

What the team was not seeing, however, were metrics like the R number that could help meet some of the policy-makers' other needs: metrics they could use to decide if and when to act, and to justify to the public why potentially unpopular choices might be necessary (see **Figure 3**).

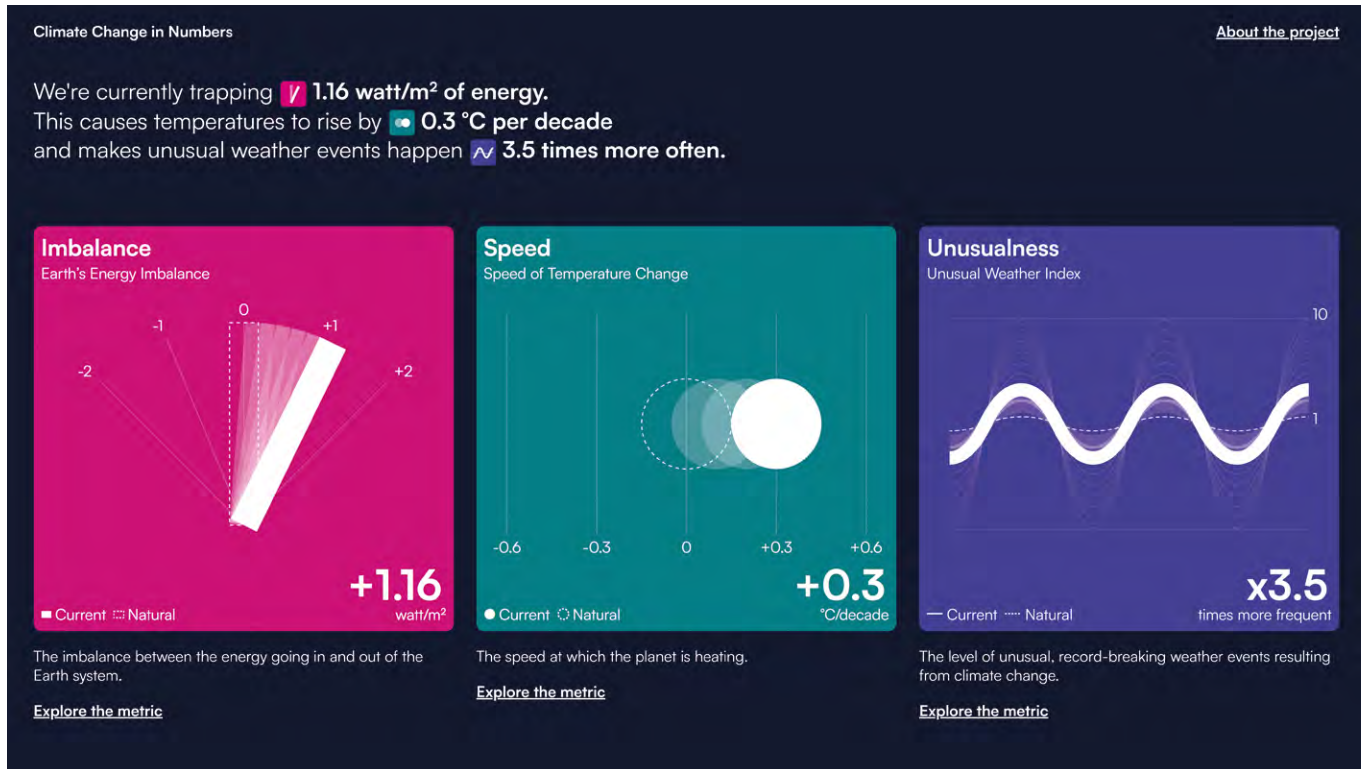
DISCOVERY ENDS, APPLICATION BEGINS

The CAU team ultimately spent several months analysing experts' opinions and interrogating the way climate metrics were used across society. At the end of this, the CAU was invited to see what could be achieved by building a new set of climate metrics.

The team's approach – rich with the research learnings – turned the usual process of constructing metrics on its head. Rather than create metrics based on available data, they started by asking what needs a modern climate metric should fulfil. They weighed up what features would be necessary to best serve that purpose, and questioned what trade-offs existed between the communicability of a metric and its scientific robustness. Only then did they look at what datasets could power these new communication tools.

Once finalised, the metrics were introduced to selected public audiences in the summer of 2023 (see **Figure 4**).

The first is Earth's energy imbalance (EEI). This is the amount of energy being trapped in the



▲ **Figure 4. A screenshot of the climatedash home page. (Source: UCL Climate Action Unit[3])**

atmosphere by greenhouse gases, unable to escape into space. The second is the speed of warming, measured in degrees Celsius per decade. The third is an unusual-weather index, showing how many more extreme heat events are occurring compared to what would be expected in a world without climate change. Viewed together, these metrics tell a story linking the physical causes of climate change with people's own experience.

These three were ultimately chosen following several rounds of scoping with scientists and communications professionals. Each round of scoping involved 'trade-off' conversations about what is possible to achieve with the data available and what would make a metric most desirable to use. One trade-off was deciding what time period to use when calculating the speed of temperature change. From year to year, temperatures fluctuate naturally. But on top of this, there is an overall upward trend. Because of that natural variability in the climate system, scientists need to average over a long enough period before the trend becomes visible – before the signal emerges from the noise.

The team had to decide what averaging period would be long enough to robustly show the warming trend, while not being so long that it feels unconnected to people's lives. Research has shown that people have an experiential memory of around the last three years for weather, so a 10-year average would better match people's lived experience than, say, a 30-year average.

WORKING WITH DESIGN PROFESSIONALS

Metaphorically speaking, at this stage in the project all the necessary ingredients were available to create some new climate metrics but there was no recipe or chef. To resolve this, the team partnered with a community of data journalists and designers. Their expertise enabled the CAU to build interactive, visual representations of each concept on an online dashboard – a platform that could interact with any dataset.

At this stage several conscious design choices were made to enhance the communicability of the metrics. It was important, for example, that the visuals could show the ideal state alongside the actual value for a given metric. Shapes were also used to convey the meaning of the scientific concept behind each metric. For example, the EEI metric looks like a domino tipping over: falling off balance (see **Figure 5**).

Some very intentional choices were also made about the use of colour. It is common for climate metrics to use a colour scale of green to red. But consider the feelings that the colour red can evoke; it is a colour commonly associated with danger. The team did not want these metrics to stimulate a fear response in users, and for good reason: social sciences and neuroscience research suggests that fear is an unpredictable, unreliable mechanism for motivating people to act.[4,5]

It is true that for some a feeling of fear can lead to action. But for others, that feeling of fear can trigger them to disengage, to bury their heads in the sand or to feel hopeless about a situation. In some people, fear evokes a denial response.[6] That is the opposite of what these metrics sought to achieve. The purpose of the project was to create metrics that people could repeatedly engage with. Sustained use of a metric is what helps it gain meaning for people.

CLIMATEDASH TODAY

Today, these metrics are freely available to access online as a static prototype.[3] The website (Climatedash.org) explains how we are currently trapping 1.16 watts of energy for every square metre of the Earth's surface, which is causing it to warm at a speed of 0.3C per decade and makes unusual weather events happen 3.5 times more often. Dashboard users can click on each metric for an explanation and interrogate how the values change over different spatial and temporal resolutions. They can get details about the units of measurement and find out why each metric is worth caring about.

This prototype dashboard has already been tested with a range of users and has proven to be particularly interesting to the media.[7-9] But for the media to adopt these metrics into their operations

▲ **Figure 5. A screenshot showing the use of colour in the climatedash metrics. (Source: UCL's Climate Action Unit[3])**

CASE STUDY

and programming, further work is still needed. One such area is getting the data that powers the metric to update more regularly. Unlike Covid-19 data, which were updated more or less daily, there is a lag of several months before climate data are published. This is the time it takes for the scientific community to process and accumulate the datasets. For the media sector to use the metrics, a daily or weekly updated platform is necessary, much like with the R number. For journalists to want to tell a story of how a particular event is linked to climate change, they need up-to-date, reliable metrics.

Another area of further work is to look at other types of weather extremes. At present, the 'unusualness' metric reflects extreme heat days. But it would be possible for a metric to capture other extremes, such as rainfall or wind speed. The limitations here are the lack of sufficient data to be able to make robust comparisons and not having the resources to do the modelling work (which was what allowed the CAU team to compare actual values to a simulated world without climate change).

The ultimate goal, though, would be to develop additional metrics. The CAU's shortlist includes one that would show progress in tackling climate change, and another that reflects the impact of climate change on people (such as labour productivity or human health).

Freya Roberts is the Project Manager of the climate change work happening at the UCL Climate Action Unit. She oversees the team's portfolio of projects, core operations and communications. Her academic background is in environmental sciences and communicating about climate change.

Lucy Hubble-Rose is the Deputy Director of the UCL Climate Action Unit. She is an expert facilitator specialised in helping professionals to unpick the difficult problems associated with achieving action on climate change. She has a PhD in climate change engagement from the University of Exeter.

Kris De Meyer is the Director of the UCL Climate Action Unit. He is a neuroscientist and science communicator, bringing insights from neuroscience and psychology to the domain of climate change. Kris specialises in how people become entrenched in their beliefs, how polarisation occurs and how to overcome it.

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REFERENCES

1. Worland, J. (2016) Global CO2 concentration passes threshold of 400 ppm – and that's bad for the climate, *Time*, 24 October. https://time.com/4542889/carbon-dioxide-400-ppm-global-warming/ (Accessed: 15 May 2025).
2. UK Government (2020) *Steps of adjustment to current social distancing measures.* https://assets.publishing.service.gov.uk/media/5eb98dddd3bf7f5d3c74a2de/slides_-_11_05_2020.pdf (Accessed: 31 March 2025).
3. Climate Action Unit (no date) Home page. https://www.climatedash.org/ (Accessed: 1 May 2025).
4. De Meyer, K., Coren, E., McCaffrey, M. and Slean, C. (2020) Transforming the stories we tell about climate change: from 'issue' to 'action'. *Environmental Research Letters*, 16 (article: 015002). https://iopscience.iop.org/article/10.1088/1748-9326/abcd5a (Accessed: 1 May 2025).
5. Witte, K. and Allen, M. (2000) A meta-analysis of fear appeals: implications for effective public health campaigns. *Health Education & Behavior*, 27 (5), https://doi.org/10.1177/109019810002700506 (Accessed: 1 May 2025).
6. Aronson, E. (2008) Fear, denial, and sensible action in the face of disasters. *Social Research: An International Quarterly*, 75 (3), pp. 855–872. https://www.jstor.org/stable/40972094 (Accessed: 1 May 2025).
7. Netzwerk Klima Journalismus (2022) *Kris de Meyer: Angst zu machen ist kein guter Ratschlag.* https://www.klimajournalismus.at/interviews/kris-de-meyer-angst-zu-machen-ist-kein-guter-ratschlag/ (Accessed: 31 March 2025).
8. Geere, D. (2023) *New climate metrics for new climate conversations.* https://datajournalism.com/read/longreads/new-climate-metrics-for-new-climate-conversations (Accessed: 1 May 2025).
9. Financial Times (2022) *'Magic numbers' are clouding the climate debate*, 24 October. https://www.ft.com/content/7e047a60-c2eb-47ed-b6bf-fff4260079c9 (Accessed: 1 May 2025).

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The challenges of natural beauty measurement

Sally Marsh ponders whether we can apply metrics to the beauty of nature.

Metrics have come to dominate environmental policy in the 21st century, but it has not always been like this. In 1949, UK legislation sought to preserve and enhance natural beauty across extensive areas of countryside.[1] These areas became our National Landscapes (previously Areas of Outstanding Natural Beauty or AONBs) and National Parks, which now cover 25 per cent of England and Wales. They were not ranked or rated for their beauty; all were considered equally beautiful in their own way. Their nature-rich countryside, managed by traditional human-scale agriculture, was celebrated by society as places where current and future generations could seek and experience the beauty of nature. Their protection from harm was seen as a moral duty.

OPINION

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Government at the time assumed that this harmony between land management and nature would persist and continue to co-create colourful meadows, moorland, wetland and woodland rich in wildlife and alive with the sounds of birds and insects. Seventy-five years later, it appears that implementation of the legislation has been only partially successful: protecting cultural landscape character by shielding these areas from the worst excesses of late 20th-century urbanisation but failing to halt harm to nature from industrial-scale agriculture and lax regulation of air, soil and water quality. The government insists that setting measurable targets, rather than system or behavioural change, will solve the problem. But the history of natural beauty measurement suggests that more attention to theory will be needed if metrics are to play a useful role.

MEASURING NATURAL BEAUTY

A desire to measure natural beauty arose in the 1960s and 70s when quantitative evaluation methods were developed for abstract values (such as beauty) to trade them with commodities (such as timber) in land-use planning decisions. The shift in focus was prompted by a more systematic approach to planning and increasing dominance of economic theories, which equated value with price, together with public policy management beliefs that setting performance targets would result in increased public value.

Daniel and Boster's scenic beauty estimation method was developed in 1976 as an early technique to measure natural beauty.[2] Based on participants rating scenes, it is still in use today. Scenic beauty assessment reached its zenith

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with a Warwick Business School study in 2017 that asked people to rate over 200,000 images of Great Britain on a scale of 1–10 (not scenic to very scenic).[3] Analysis of results against the image qualities prompted media headlines such as 'computer trained to determine what makes places beautiful', suggesting that the study could underpin better settlement planning.[4]

Scenic beauty assessments are part of a genre of aesthetic preference and landscape quality studies, which do not necessarily share a consistent aesthetic theory or agreed set of definitions and terminology.[5] While there are undoubtedly useful outputs from such studies, it is difficult to claim that they tell us anything meaningful about beauty as an aesthetic value. Beauty is not something that lends itself to easy measurement.[6] As soon as it is ranked or rated it ceases to be about beauty and, instead, tends to become an indication of preference for a different combination of qualities, such as place or image composition.

Preference studies are common in natural beauty research, with ratings choices usually made in an indoor setting looking at a framed image from a fixed distance. Such studies are cheaper, and control of variables is easier than in the real world, but this limits the information that can be gained. Sense perception tends to be restricted to the visual, snap judgements (e.g. like/dislike) are common and the role that emotional engagement with nature plays is overlooked. Researchers have sought to correlate preference with formal qualities such as land-cover patterns or visual or ecological condition, but this is only meaningful if we assume an evolutionary origin for aesthetic preference.[7] Such an origin remains contested, with cultural and individual experiences offered as alternative factors.[8]

THE IMPORTANCE OF AESHETIC THEORY

If we wish to measure the beauty of nature (or landscape) in the real world, the experience is not one that can be captured by a static image. Aesthetic theory helps us understand the difference.[9] A natural beauty experience involves a dynamic relationship between perceiver and object. The perceiver is an integral part of the object, not an external spectator, and this holds true even if we are standing on a mountain turning our attention to a specific view.[10] 'Natural (nature)' – or 'landscape/scenic' – are descriptors that encompass and describe the object our senses and cognition engage with in a beauty experience. What distinguishes such experiences as aesthetic ones is the role of positive emotions – described by Immanuel Kant as disinterested pleasure. This is pleasure in nature not linked to any utilitarian purpose such as trading nature for another benefit.[11,12]

In real-world environments, natural beauty is often a prolonged aesthetic experience mediated by movement and exposed to the effects of temporal changes such as light and weather.[13]

Like any perceptual experience, beauty starts with engagement of all the senses. As we move, the boundary of what we notice moves with us as the body senses changes in the environment through the skin, constantly adjusting and re-adjusting the detail and scope of what we see and hear.

Neuroscience describes beauty as an emergent mental state arising from the interaction of three neutral systems: sensory–motor (sensation, perception, motor system); emotion–valuation (reward, emotion, wanting/liking), and knowledge–meaning (expertise, context and culture).[14] What aspect of the object we engage with can differ between moments and between people sharing the same moments. We suspect that the richer an environment is in wildlife and bio-abundance, the greater the opportunities for a deeper natural beauty experience. But the difference in baselines between individuals, cultures, generations and environments make this a difficult subject to test.

MODELS FOR MEASURING NATURAL BEAUTY

The complexity of natural beauty suggests that if we want to quantify it, we need to create an approximation – a simplified model – underpinned by aesthetic theory. Such a model would need to take account of both the object's qualities (the characteristics of nature or landscape as a dynamic system) and the emotions and experience of individuals immersed in it. Inevitably, as a

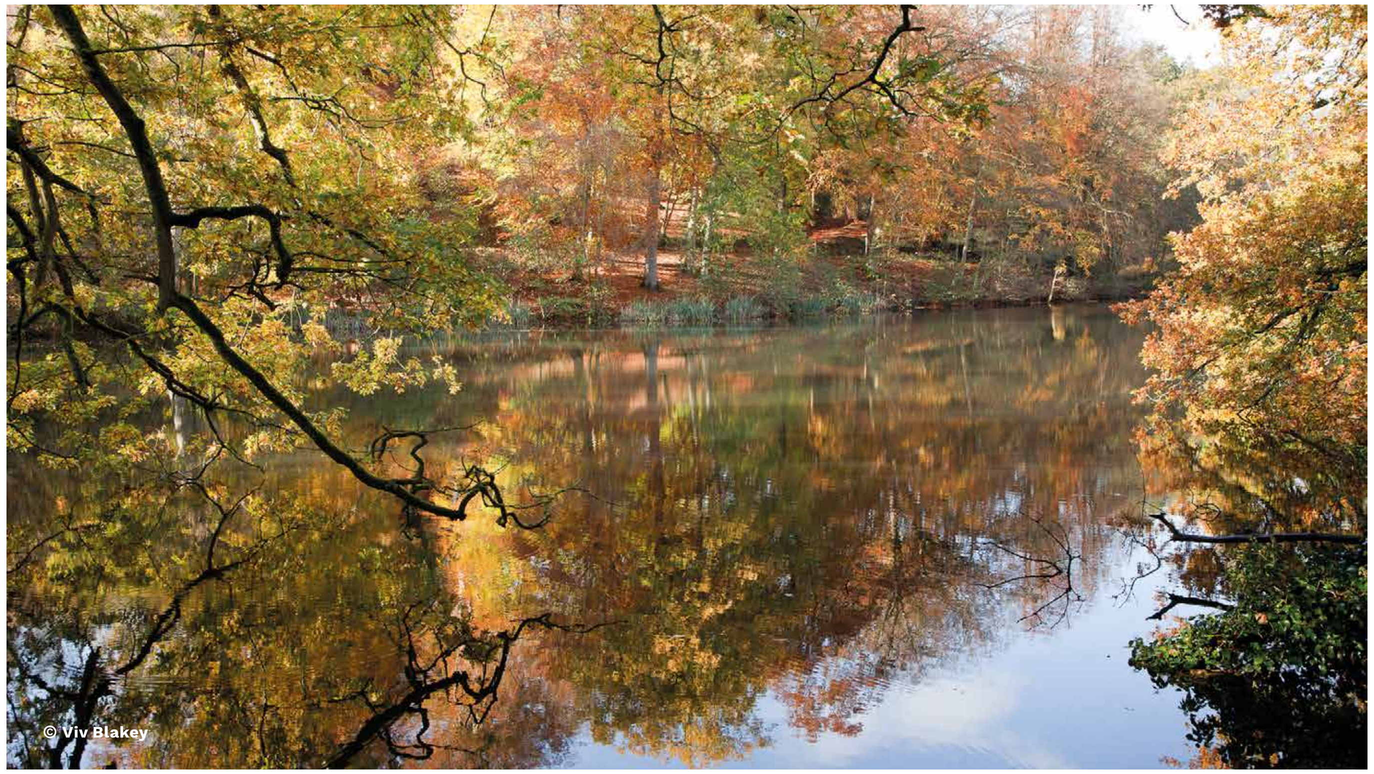
simplification of the real world, a model is likely to exclude critical factors, foreground some factors over others and obscure attributes that cannot be easily categorised for measurement. To give confidence to decision-makers, an explanatory narrative will be necessary to help users understand the conceptual framework underpinning the choices made, how the model relates to the real world and where uncertainty lies.[15]

In practice, the tricky task of navigating theory, testing outputs against the real world, and acknowledging assumptions and uncertainties tends to be ignored in what is an increasingly time- and resource-poor policy environment. Today, the main model used to take account of natural beauty in policy rests on reframing natural beauty as landscape that is interpreted as either a large site or static scene. Landscape assessment (described as a systematising of aesthetics) overtook scenic beauty assessment as a planning tool in the 1980s.[16]

Today, six qualities developed to attribute value to a character area unit in landscape assessment are used to underpin natural beauty evaluation for monitoring purposes and to identify areas rich in natural beauty for potential designation. These six qualities are scenic quality, natural heritage, cultural heritage, landscape quality, relative wildness and tranquillity.[17–20] Perhaps it was inevitable that the government body responsible for natural beauty would adopt an off-the-shelf method. Yet gradually, these six factors have acquired an authority without any explanatory narrative that links them to aesthetic theory. Questions such as why these six factors and not others and why some factors are weighted more heavily than others remain unexplained.

The continuing challenge of natural beauty measurement is demonstrated by the paucity of data provided by government to support Goal 10 of its Environment Improvement Plan: 'Enhancing beauty, heritage and engagement with the natural environment'.[21] Data are provided on visits to green spaces, pro-environmental behaviours and frequency of time spent outside – presumably proxy indicators – but no information is offered on people's experience of beauty in nature.

In the absence of a consistent approach to measuring natural beauty, other established methods have been drawn upon to fill gaps, each bringing its own set of strengths and weaknesses. For landscape and visual impact assessment, commonly used to assess harm to natural beauty in planning decisions, the key weakness is visual bias. Biodiversity net gain, which uses a government metric to justify contributions from developers to nature recovery targets in Protected Landscapes, remains untested against



real-world biodiversity and fails to take account of alternative scenarios, such as what habitats might become if left alone.[22]

Currently, all these models ignore or downplay the dynamic and multi-scalar nature of the object in natural beauty and, in their stand-alone substitution for natural beauty, exclude information on people's experiences of it. An emotional response to nature tends to be distrusted in laypeople and decision-makers in favour of data and expert judgement, which are considered more objective. However, in natural beauty, emotion and the complex interplay between cognition and knowledge are as important as the physical object, suggesting that there is no such thing as an objective assessor.[23]

ALTERNATIVES TO MEASUREMENT

If targets and metrics fail to capture the breadth and wonder of natural beauty, is there an alternative? We could choose not to measure it. Instead, we could, as the writer and philosopher Aldo Leopold proposed, judge our actions against whether they 'preserve the integrity, stability and beauty of the biotic community'.[24]

We could explore other ways to take account of it in policy, drawing on new information such as soundscape data to inform our actions, or work with other disciplines to bring a richer and deeper understanding of people's experiences of natural beauty to policy. Ethnographic work with fell runners in the Lake District, corpus analysis of online first-person nature experiences, and art, dance, music and ritual-based expression of the beauty of nature can all contribute.[25,26]

While we continue to create a more meaningful dashboard of indicators and information to help consider natural beauty in policy decisions, perhaps it is also worth remembering that the wonderful landscapes celebrated for their natural beauty were not shaped by metrics. Their natural beauty was a by-product of their function over centuries as working countryside producing food and raw materials. Policies to support people to engage emotionally with nature and move to a modern circular economy, managing these landscapes regeneratively and productively in a non-industrial, low-carbon, chemical-free way, may achieve more for nature and natural beauty than the current focus on measured targets.[27] ES

Dr Sally Marsh is a landscape ecologist and Fellow of the Landscape Institute. She has been Co-Director of the High Weald National Landscape Partnership for over 30 years and is a member of Natural England's Landscape Advisory Panel.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REFERENCES

1. UK Public General Acts (1949) National Parks and Access to the Countryside Act. https://www.legislation.gov.uk/ukpga/Geo6/12-13-14/97 (Accessed: 2 May 2025).
2. Daniel, T.C. and Boster, R.S. (1976) *Measuring Landscape Esthetics: The Scenic Beauty Estimation Method.* USDA Forest Service, Research Paper RM-167, US Department of Agriculture. https://www.fs.usda.gov/rm/pubs_rm/rm_rp167.pdf (Accessed: 2 May 2025).
3. Seresinhe, C.I., Preis, T. and Moat, H.S. (2017) Quantifying scenic areas using crowdsourced data. *Environment and Planning B: Urban Analytics and City Science*, 45 (3), pp. 567–582. https://doi.org/10.1177/0265813516687302 (Accessed: 2 May 2025).
4. Sample, I. (2017) Beauty spot or landscape blot? Computer trained to judge scenery, *The Guardian*, 19 July. https://www.theguardian.com/science/2017/jul/19/beauty-spot-or-landscape-blot-computer-trained-to-judge-scenery (Accessed: 2 May 2025).
5. Bourassa, S.C. (1991) *The Aesthetics of Landscape.* London: Belhaven Press.
6. Born, T. (1974) Measuring natural beauty: the problem of quantification. *Progressive Agriculture in Arizona*, 26 (5), pp. 14–16. http://hdl.handle.net/10150/300538 (Accessed: 2 May 2025).
7. Appleton, J. (1984) Prospects and refuges re-visited. *Landscape Journal*, 3 (2), pp. 91–103. https://doi.org/10.3368/lj.3.2.91 (Accessed: 2 May 2025).
8. Nassauer, J.I. (1995) Culture and changing landscape structure. *Landscape Ecology*, 4 (10), pp. 229–237. https://doi.org/10.1007/BF00129257 (Accessed: 2 May 2025).
9. Jenkins, V. (2020) In defence of natural beauty: aesthetic obligation and the law on the designation of protected landscapes in England and Wales. *Environmental Law Review*, 22 (1), pp. 7–24. https://doi.org/10.1177/1461452919900345 (Accessed: 2 May 2025).
10. Berleant, A. (2012) The art in knowing a landscape. *Diogenes*, 59 (1–2), pp. 52–62. https://doi.org/10.1177/0392192112469320 (Accessed: 2 May 2025).
11. Kant, I. (1951) *Critique of Judgement.* Translated by J.H. Bernard. New York: Hafner Publishing Co.
12. Brady, E. (2003) *Aesthetics of the Natural Environment.* Edinburgh: Edinburgh University Press.
13. Ingold, T. (2000) *The Perception of the Environment. Essays on Livelihood, Dwelling and Skill.* London and New York: Routledge.
14. Chatterjee, A. and Vartanian, O. (2016) Neuroscience of aesthetics. *Annals of the New York Academy of Sciences, 1369* (1), pp. 172–194. https://doi.org/10.1111/nyas.13035 (Accessed: 2 May 2025).
15. Thompson, E. (2022) *Escape from Model Land: How Mathematical Models Can Lead Us Astray and What We Can Do About It.* London: Basic Books.
16. Price, C. (2017) *Landscape Economics*, 2nd edn. Switzerland: Palgrave Macmillan.
17. Swanwick, C. (2002) *Landscape Character Assessment: Guidance for England and Scotland.* Report to the Countryside Agency and Scottish Natural Heritage.
18. Land Use Consultants (2022) *All-England strategic landscape mapping tool.* Final report. Natural England. https://www.landuse.co.uk/projects/all-england-strategic-landscape-mapping/ (Accessed: 12 May 2025).
19. Bingham, L. (2014) *Framework for Monitoring Environmental Outcomes in Protected Landscapes.* Natural England Research Reports, NERR055. https://publications.naturalengland.org.uk/file/6707256733204480 (Accessed: 2 May 2025).
20. Natural England (2011) *Guidance for Assessing Landscapes for Designation as National Park or Area of Outstanding Natural Beauty.* https://consult.defra.gov.uk/natural-england/suffolk-coast-and-heaths-aonb/supporting_documents/Guidance%20for%20assessing%20landscapes%20for%20designation%20as%20National%20Park%20or%20AONB%20in%20England.pdf (Accessed: 2 May 2025).
21. Office for Environmental Protection (2025) *Progress in improving the natural environment in England 2023–2024.* Speech by Dame Glenys Stacey, Chair of the OEP, 16 January. https://www.theoep.org.uk/news/progress-improving-natural-environment-england-2023-2024-speech-dame-glenys-stacey-chair-oep (Accessed: 2 May 2025).
22. Department for Environment, Food & Rural Affairs (2024) *Protected Landscapes Targets and Outcomes Framework.* https://www.gov.uk/government/publications/protected-landscapes-targets-and-outcomes-framework/protected-landscapes-targets-and-outcomes-framework (Accessed: 5 May 2025).
23. Jacques, D. (2021) Neuroaesthetics and landscape appreciation. *Landscape Research*, 46 (1), pp. 116–127. https://doi.org/10.1080/01426397.2020.1832204 (Accessed: 2 May 2025).
24. Leopold, A. (1949) *A Sand County Almanac.* New York: Oxford University Press.
25. Koblet, O. and Purves, R.S. (2020) From online texts to landscape character assessment: collecting and analysing first-person landscape perception computationally. *Landscape and Urban Planning*, 197 (article: 103757). https://doi.org/10.1016/j.landurbplan.2020.103757 (Accessed: 2 May 2025).
26. Nettleton, S. (2015) Fell runners and walking walls: towards a sociology of living landscapes and aesthetic atmospheres as an alternative to a Lakeland picturesque. *British Journal of Sociology*, 66 (4), pp. 759–778. https://doi.org/10.1111/1468-4446.12146 (Accessed: 2 May 2025).
27. Lumber, R., Richardson, M. and Sheffield, D. (2017) Beyond knowing nature: contact, emotion, compassion, meaning, and beauty are pathways to nature connection. *PLoS ONE*, 12 (5), article: e0177186. https://doi.org/10.1371/journal.pone.0177186 (Accessed: 2 May 2025).

ANALYSIS

The future of the UK's biodiversity indicators

Steve Wilkinson analyses the challenges and opportunities of applying indicators in policy development.

The UK maintains a suite of biodiversity indicators, providing a summary of how biodiversity, and some of the key factors impacting it, change through time.[1] The primary driver for the maintenance of these indicators has been to demonstrate progress against international commitments, particularly those under the Convention on Biological Diversity.[2] The majority of the responsibility for delivery of these commitments is devolved to the four nations with the indicators showing how the UK as a whole is progressing. As these commitments have evolved through time, the suite of indicators has been adjusted accordingly.

Marbled white butterfly | © Helen Baker

THE LINK BETWEEN INDICATORS AND POLICY

While being able to demonstrate progress against international commitments remains important, with tightening public finances there is an increasing need to begin to extract more value from reporting commitments. A key issue is that there is often an insufficiently strong link between broader reporting obligations and domestic policies (i.e. for each of the four nations), resulting in the development of other indicators of domestic progress that are more relevant to national governments. Additionally, changes in outcomes through investments are often slow to be realised and there is currently a very weak ability to project what the expected changes from investment will be on either domestic or UK-wide indicators. Moving to a suite of indicators that can more directly inform policy would substantially improve their value.

Within a UK context there is an enhanced opportunity to gain insight from consistent indicators. Since the UK's departure from the EU there has been increasing divergence of policies across the four UK nations. This divergence provides an opportunity, creating a sort of 'policy lab', where the effectiveness of different policies can be tracked and assessed across a relatively consistent biogeographical zone. This insight is most robustly realised through consistent measurement of outcomes across the four nations. How can these existing UK indicators be developed to generate a reporting structure and approach that provides greater power and insight to inform the development of environmental policies?

SHARED OUTCOMES ACROSS POLICIES

The nature in the UK (i.e. species, habitats and their relative abundance) is ultimately a reflection of everything that affects the environment. This means that we cannot consider what our future nature looks like without thinking about the overall balance of what we want as a society. These broad societal benefits include things such as meeting net zero commitments, maintaining a healthy population, having a secure food, energy and water supply, being resilient to environmental shocks that are increasingly frequent because of climate change, and having sufficient housing. The natural environment is affected by the decisions on the balance of these benefits, but it also underpins many of them. As a result we are increasingly seeing more integrated policy-making – for example, the Well-being of Future Generations Act 2015 in Wales.[3]

Below these broad societal benefits there is a set of underpinning environmental outcomes such as air, water and soil quality, intensity of agricultural production, and the condition and extent of natural habitats. Despite the divergence of policies across the four UK nations, there is still a high degree of consistency in both the societal benefits and the desired underpinning environmental outcomes. How policies affect the outcomes is complex, as amplifying one policy can adversely impact another, and to inform the debate there needs to be a consistent and persistent set of outcomes whose progress is assessed using indicators.

The devolved and national UK governments are reviewed through elections at least every five years. As the natural environment can be slow to respond to changes, it is very difficult for any government to generate tangible outcomes within a single term and there is a risk that indicators within that time are more activity focused. For example, Defra's Sustainable Farming Incentive has recorded areas of arable land that are farmed without insecticides rather than the actual impact of this on pollinators and soil health, which will respond more slowly.[4] Having cross-party – and ideally cross-country – agreement on what the longer-term outcomes and associated indicators should be, alongside a commitment to maintaining a long-term assessment of these, would be a useful start. Defra's Outcome Indicator Framework is perhaps one of the most mature examples of this but there is equivalent emerging work from the four nations.[5]

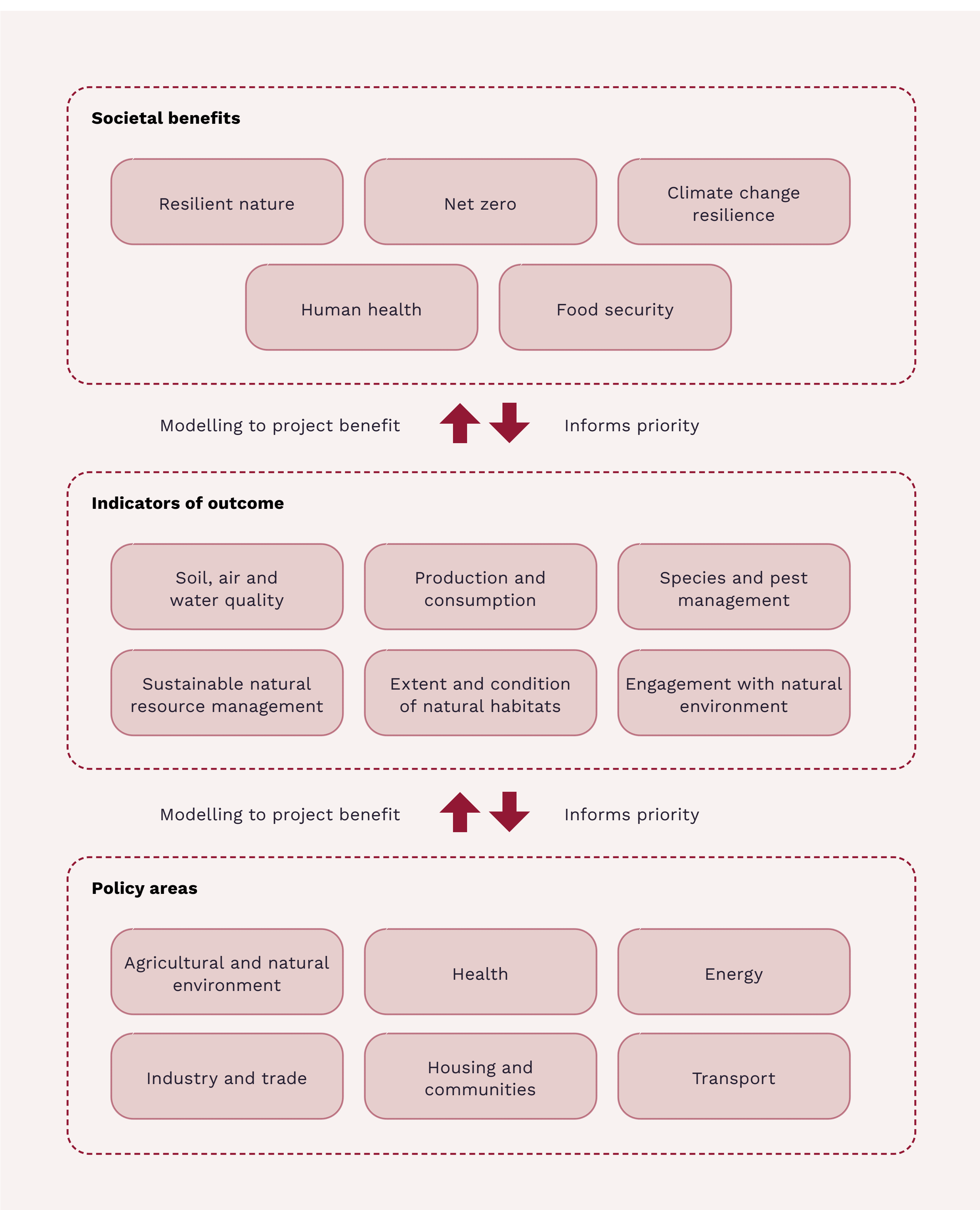
Decisions on how we use our land and sea areas and how we invest to derive the benefits are key, including how the natural environment itself contributes to the desired outcomes. For example, net zero is a societal benefit, and habitats such as peatland and woodland can help to reduce carbon emissions. However, maintaining, creating and restoring these habitats need to be traded off against other land uses including energy production, housing and agricultural outputs.

With growing appreciation across business and industry of the benefits the natural environment provides, industry will also increasingly have an interest in outcomes and how these can be enhanced.[6,7] There is an opportunity to work more closely here to align government strategies and investment with this sector.

PROJECTING THE FUTURE STATE

A key weakness of the existing UK indicator suite is that while the indicators track the current state, they do not attempt to project into the future. For example, the priority species abundance indicator has shown a steady decline before plateauing but we do not attempt to predict or show how existing policies will affect this – for example, will these species recover?[8] There are two levels to this projection. Firstly, there is projecting the impact of policy on outcomes and, secondly, there is estimating how these outcomes will affect the desired overarching societal benefits (see **Figure 1**). Such projections would serve to inform the development of policy as well as help to assess whether progress is on track. This ability, more than anything, would improve the usefulness of the indicators in informing domestic policy.

A specific aspect of this will be defining what is meant by 'nature recovery' as a societal benefit.[9-11] While there are now plenty of indicators describing nature's decline, it is impractical to think we can simply reverse the UK's natural environment back to an arbitrary point in the past. There are more people, much higher demand and consumption, and a broad range of resulting pressures, including the overarching effects of climate change, that are difficult or impossible to completely unwind. Better empirical evidence on drivers of change combined with considering the broader practicalities of how these can be adjusted will help to define some potential practical end points that we are at least nominally aiming for.



▲ **Figure 1. Schematic showing the relationship between some broader societal benefits, suite of indicators of environmental outcomes underpinning these, and policies, highlighting the enhanced role of modelling and projection to inform policy development.**

Despite the advances made in analytical techniques and the extensive evidence available across the UK, generating these future projections remains challenging.[12] As a result, the process will be iterative, using the evidence we have to begin to assess the likely future impact of policies, but also using these analyses to identify what additional evidence would help to improve the models. Tightening the integration of investment in this modelling capability across governments and research would significantly accelerate the agenda. Also, working at a UK scale, assuming there is sufficient consistency in evidence, will provide much greater power to the analyses, including integration of the impacts of climate change.

ENHANCING THE EVIDENCE

The approaches outlined above begin to frame a way for much more evidence-driven and integrated policy-making built around a set of agreed indicators. The approach is predicated on more extensive use of predictive models that are not simple to generate; however, enhancing the available evidence to inform the modelling will address this. The additional evidence needed includes details of what interventions are being made and where, as well as what outcomes these are realising.

The UK is very fortunate in the scale of the existing evidence base. It has a combination of consistent long-term monitoring data across the four nations, including the Joint Nature Conservation Committee's (JNCC) species surveillance schemes and various satellite data sources, as well as an extensive volume of experimental evidence from the research sector looking at the impact of specific pressures and interventions.[13,14] Combining these would give a much better understanding of what is driving long-term change. Emerging work in this area is already beginning to feed directly into shaping policy.

One key issue is improving the availability of government-held information on where activities have been licensed and publicly funded interventions undertaken. Part of the move to a digital government will help to standardise this sort of information. However, there is also a need to address perceived concerns and constraints around what constitutes personal data and to ensure that the data can at least be made available to those seeking to understand the effectiveness of the interventions.

A second issue is improving access to more of the data that industry, including land managers, hold and particularly what is input into, and extracted from, the environment. Data relating to these can be seen as commercially sensitive and there may be a perceived risk of being subject to regulation through publicising the information. However, without addressing this we are working with a very partial picture. Take, for example, agricultural inputs such as fertilisers and pesticides, which are now almost certainly some of the biggest drivers of change in a range of environmental outcomes, including food production, soil, water and air quality, and biodiversity. They represent one of the main outlays of land managers and, therefore, in most cases, related data are well managed but not accessible to support wider analyses.

At present there is no access to the public or research sectors to these data other than through general proxies such as Defra's farm survey.[15] This needs to change, through improving the collaboration between government and industry and potentially adjusting regulation to maintain a level playing field and move to more strategic approaches that maximise the use of existing evidence to improve assessments of outcome, agree the direction and scale of travel, and allow industry to operate with greater certainty.

Thirdly, as the models emerge, they will have weaknesses: aspects where the ability to project into the future is weaker. Clarifying these and identifying the evidence that is needed to address them should also direct how evidence gathering needs to be enhanced. This should inform shared monitoring strategies straddling government and industry.

Lastly, there is a need for a more strategic and collaborative approach to monitoring. Monitoring outcomes is expensive, and public spend in this area is likely to come under increasing scrutiny. Much of the existing investment is driven by specific regulatory obligations that do not necessarily align with evidence needs.

▲ **A Seabird Monitoring Programme volunteer collecting data as part of the scheme run in partnership between JNCC, BTO and RSPB. © Matt Parsons**

Advances including the use of satellite imagery and engagement with other sectors (including citizens) to capture evidence have provided alternative ways to generate robust and cost-effective change signals (e.g. Defra's Natural Capital and Ecosystem Assessment programme[16]). There needs to be much better coordination across all sectors to optimise investment in monitoring and to generate the maximum insight.

SUMMARY

As we move to increasing integration of the natural environment within broader policies in the delivery of overall societal demands, we need to identify a set of environmental outcomes with associated robust indicators for assessing state and change. More collective and coordinated investment to develop these outcome indicators and project them into the future based on policy will really accelerate the agenda and inform the broader debate about what sort of balance is possible. ES

Steve Wilkinson is Director of Ecosystem Evidence and Advice at the JNCC. He has a background in marine ecology but specialised in analytics and data mobilisation. He is interested in driving enhanced use of evidence within government policy-making and in strengthening collaboration across UK government and industry.

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REFERENCES

1. Joint Nature Conservation Committee (2024) *UK biodiversity indicators.* https://jncc.gov.uk/our-work/uk-biodiversity-indicators (Accessed: 28 April 2025).
2. Convention on Biological Diversity (no date) Home page. https://www.cbd.int/ (Accessed: 28 April 2025).
3. Welsh Government (2015) *The well-being of future generations.* https://www.gov.wales/well-being-of-future-generations-wales (Accessed: 28 April 2025).
4. Department for Environment, Food & Rural Affairs (2025) *An update on the Sustainable Farming Initiative.* https://defrafarming.blog.gov.uk/2025/03/11/an-update-on-the-sustainable-farming-incentive/ (Accessed: 9 May 2025).
5. Department for Environment, Food & Rural Affairs (no date) *Outcome Indicator Framework for the 25 Year Environment Plan.* https://oifdata.defra.gov.uk/ (Accessed: 1 May 2025).
6. World Economic Forum (2020) *Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy.* New Nature Economy series. https://www3.weforum.org/docs/WEF_New_Nature_Economy_Report_2020.pdf (Accessed: 30 April 2025).
7. Taskforce on Nature-related Financial Disclosures (2023) *Recommendations of the Taskforce on Nature-related Financial Disclosures.* https://tnfd.global/wp-content/uploads/2023/08/Recommendations-of-the-Taskforce-on-Nature-related-Financial-Disclosures.pdf?v=1734112245 (Accessed: 30 April 2025).
8. Joint Nature Conservation Committee (2024) *Status of priority species: relative abundance.* https://jncc.gov.uk/our-work/ukbi-priority-species-abundance/#key-results-figure-1-trend-in-the-relative-abundance-of-priority-species-in-the-uk-1970-to-2021 (Accessed: 9 May 2025).
9. Wartmann, F.M. and Lorimer, J. (2024) Messy natures: the political aesthetics of nature recovery. *People and Nature*, 6 (6), pp. 2564–2576. https://doi.org/10.1002/pan3.10743 (Accessed: 30 April 2025).
10. Dobson, A.P., Bradshaw, A.D. and Baker, A.J.M. (1997) Hopes for the future: restoration ecology and conservation biology. *Science*, 277 (5325), pp. 515–522. DOI: 10.1126/science.277.5325.515.
11. Jones, H.P. and Schmitz, O.J. (2009) Rapid recovery of damaged ecosystems. *PLoS ONE*, 4 (5), article: e5653. https://doi.org/10.1371/journal.pone.0005653 (Accessed: 30 April 2025).
12. Urban, M.C., Travis, J.M.J., Zurell, D. *et al.* (2022) Coding for life: designing a platform for projecting and protecting global biodiversity, *BioScience*, 72 (1), pp. 91–104. https://doi.org/10.1093/biosci/biab099 (Accessed: 30 April 2025).
13. Joint Nature Conservation Committee (2024) *Terrestrial monitoring schemes.* https://jncc.gov.uk/our-work/terrestrial-monitoring-schemes/ (Accessed: 9 May 2025).
14. Joint Nature Conservation Committee (2019) *Making best use of Earth observation data.* https://jncc.gov.uk/monitoring/earth-observation/ (Accessed: 9 May 2025).
15. Department for Environment, Food & Rural Affairs (2025) *Farm business survey.* Data series, 5th release. https://www.gov.uk/government/collections/farm-business-survey (Accessed: 30 April 2025).
16. Department for Environment, Food & Rural Affairs (2022) *Natural capital and ecosystem assessment programme.* Policy paper. https://www.gov.uk/government/publications/natural-capital-and-ecosystem-assessment-programme (Accessed: 30 April 2025).

TECHNICAL

The Environmental Sustainability Gap framework

Paul Ekins and **Arkaitz Usubiaga-Liaño** outline the framework's two indices of national environmental sustainability.

Almost everyone these days professes to be in favour of sustainability. To be anti-sustainability would be a very curious position. However, much confusion arises given the different ways in which sustainability is characterised and defined. This confusion cannot be resolved without clearly specifying: sustainability of *what*?

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DEFINING SUSTAINABILITY

The most common answer to this question is sustainability of development, which explains the importance given to the idea of sustainable development. Yet such a characterisation introduces further complexity because the idea of development itself has long been the subject of debate and disagreement; this was only partially resolved at the international level in 2015 with the global agreement of the Sustainable Development Goals (SDGs).

This resolution was only partial because, with 17 SDGs, 169 targets and 230 separate indicators, it is impossible to say whether any country has achieved or is moving towards or away from sustainability.[1] The SDGs, and their targets and indicators, have economic, social and environmental dimensions, any of which may indicate improvement or deterioration in the state of affairs. There is also no agreed methodology to determine which are more important, whether the targets adopted are ambitious enough, or how the dimensions or the indicators may be aggregated to determine overall progress, or lack of it, towards sustainable development.[2]

Given the absence of universal rules and laws to underpin the operation of human economies and societies, it seems most unlikely that it will ever be possible to definitively describe a sustainable economy or society; it may be possible at any particular time to identify one economy or society as more sustainable than another, but not whether such a characterisation will endure. However, when considering the environment, the situation may be different because the relationships between various aspects of the environment, while formidably complex, do operate according to the laws of the natural sciences (physics, chemistry and biology). We may not fully understand these laws and relationships, but we know a lot about how they work, so that it is possible to conceive of a state of environmental sustainability that commands wide scientific agreement in the same way that the concepts of gravity, radiation and evolution do.

STRENGTH OF ENVIRONMENTAL SUSTAINABILITY

One influential way in which sustainability has been conceptualised, reflecting a desire to unify the economic, social and environmental dimensions of the idea, is through an economic lens, using the ideas of capital, investment and depreciation. This narrative builds on the idea that economic sustainability requires the maintenance or growth of the capital stock through a level of investment that is greater than its depreciation over time. Usually this capital is thought of as something that is physically produced (e.g. roads, ports, airports, energy infrastructure and buildings). However, it is possible to extend the notion to other kinds of capital – such as human (health, education), social and organisational (firms, legal and political systems, trust), and environmental or natural (natural resources and ecosystems) – recognising that in human society all these are required to some extent for economic production.

If these levels of capital can have the same unit of measurement and the total can be maintained at a certain rate or level, then it may be said that, overall, sustainability has been achieved. Both the United Nations Environment Programme and the World Bank have undertaken exercises of this sort, with money being the metric through which physically produced human and natural capitals have been measured.[3,4] This is known as the weak sustainability approach.

The problem with this approach is threefold. Firstly, there is much uncertainty as to how natural capital, especially, should be measured in monetary terms. Secondly, the values for natural capital depreciation that are derived tend to be much smaller than the investments in physically produced and human capital, especially in wealthier countries (broadly, the developed world), so that these countries emerge universally as sustainable (because their net investment in a given year is positive); whereas, it is precisely these countries that consume the most resources and have the largest environmental impacts per capita across numerous environmental issues.

Thirdly, and most fundamentally, the weak sustainability approach assumes that the benefits provided by natural capital (or, more simply, nature) are basically of the same kind, such that the environmental functions that produce these benefits can be substituted by those from the other capitals. It is far from clear that this is the case with such fundamental ecosystem services as climate regulation. This has led to reservations about using the weak sustainability approach in favour of identifying planetary boundaries, with the concern being to keep human activities within a safe operating space and based on a perception that nature provides unique biophysical benefits that cannot be monetised because no other form of capital can substitute for them.[5] Therefore, these benefits need to be maintained separately at some level if humankind wants to continue to enjoy them. This is known as the strong sustainability approach.

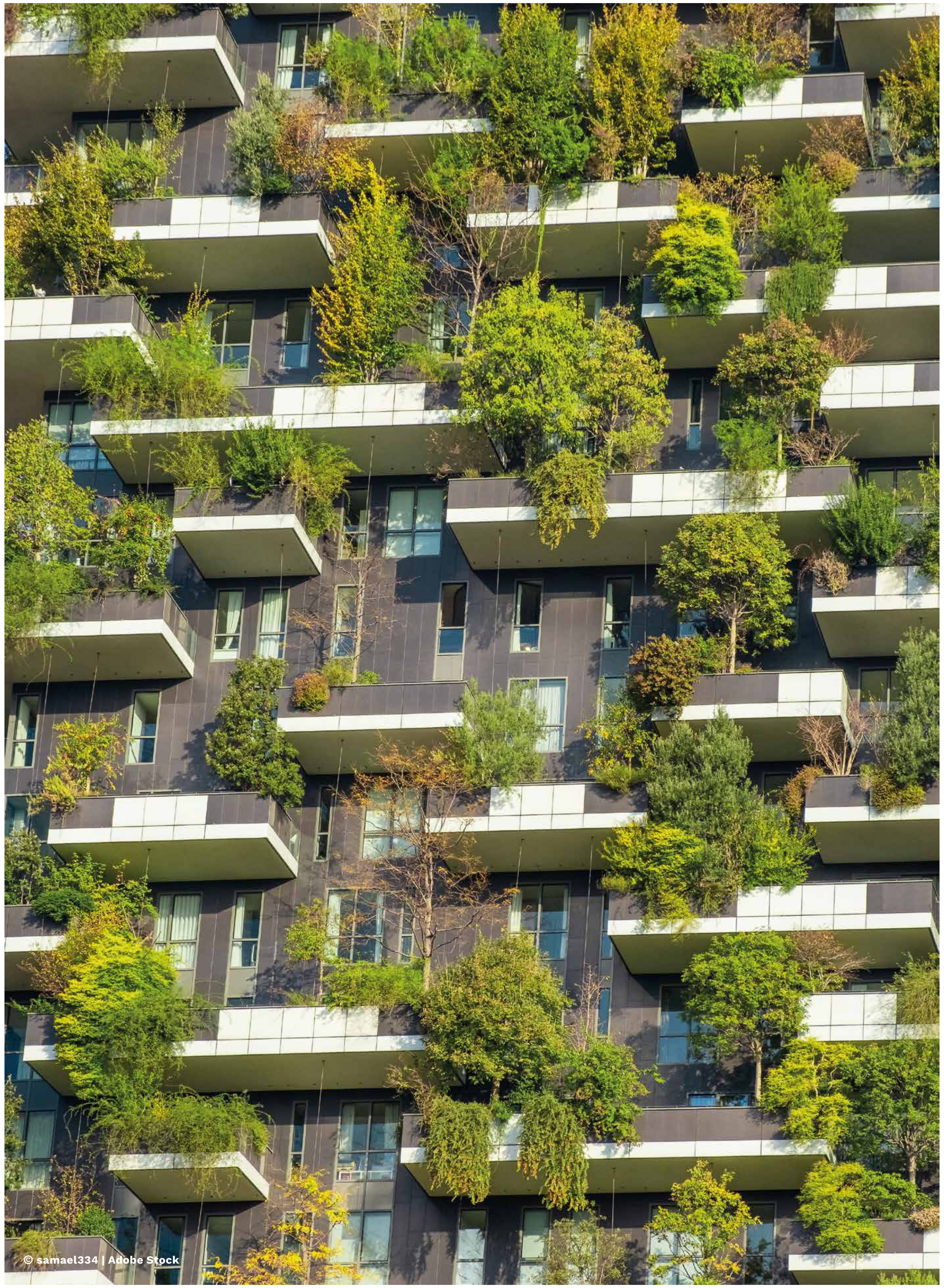
MAINTAINING ENVIRONMENTAL FUNCTIONS

If environmental sustainability is defined as the maintenance of important environmental functions, then it is necessary to specify which functions are important and to articulate principles that specify how they need to be maintained. This is the underlying basis for the Environmental Sustainability Gap (ESGAP) framework (see **Table 1**).

TABLE 1. FUNCTIONS OF NATURAL CAPITAL AND ENVIRONMENTAL SUSTAINABILITY PRINCIPLES

FUNCTION	OBJECTIVE	PRINCIPLE	PRINCIPLE
Source	Maintain the capacity to supply resources	Renew renewable resources	Maintenance of soil fertility, hydrobiological cycles, necessary vegetative cover and sustainable harvesting
		Use non-renewables prudently	Balance the depletion of non-renewable resources with the maintenance of a minimum life expectancy of the resource and the development of substitutes for it
Sink	Maintain the capacity to absorb, disperse or dilute wastes, without changing or damaging ecosystems	Prevent anthropogenic destabilisation of global environmental processes	Prevent global warming, ozone depletion
		Respect ecosystem critical levels and loads	Emissions to air, soil and water must not exceed the capability of the receiving medium to disperse, absorb, neutralise and recycle them without disturbing other functions
Life support	Maintain the capacity to sustain ecosystem health and function	Maintain biodiversity and ecosystem health	Critical ecosystems and ecological features must be protected to maintain biological diversity, which underpins ecosystems' productivity and resilience
Human health and welfare	Maintain the capacity to sustain human health and generate human welfare in other ways	Respect standards for human health	Emissions to air, soil and water must not exceed dangerous levels for human health
		Conserve landscapes and amenity	Natural capital elements of special human or ecological significance, because of their rarity, aesthetic quality, recreational values, or cultural or spiritual associations, should be preserved

(Source: Adapted from Usubiaga and Ekins, 2021a[6])



ENVIRONMENTAL SUSTAINABILITY INDICES

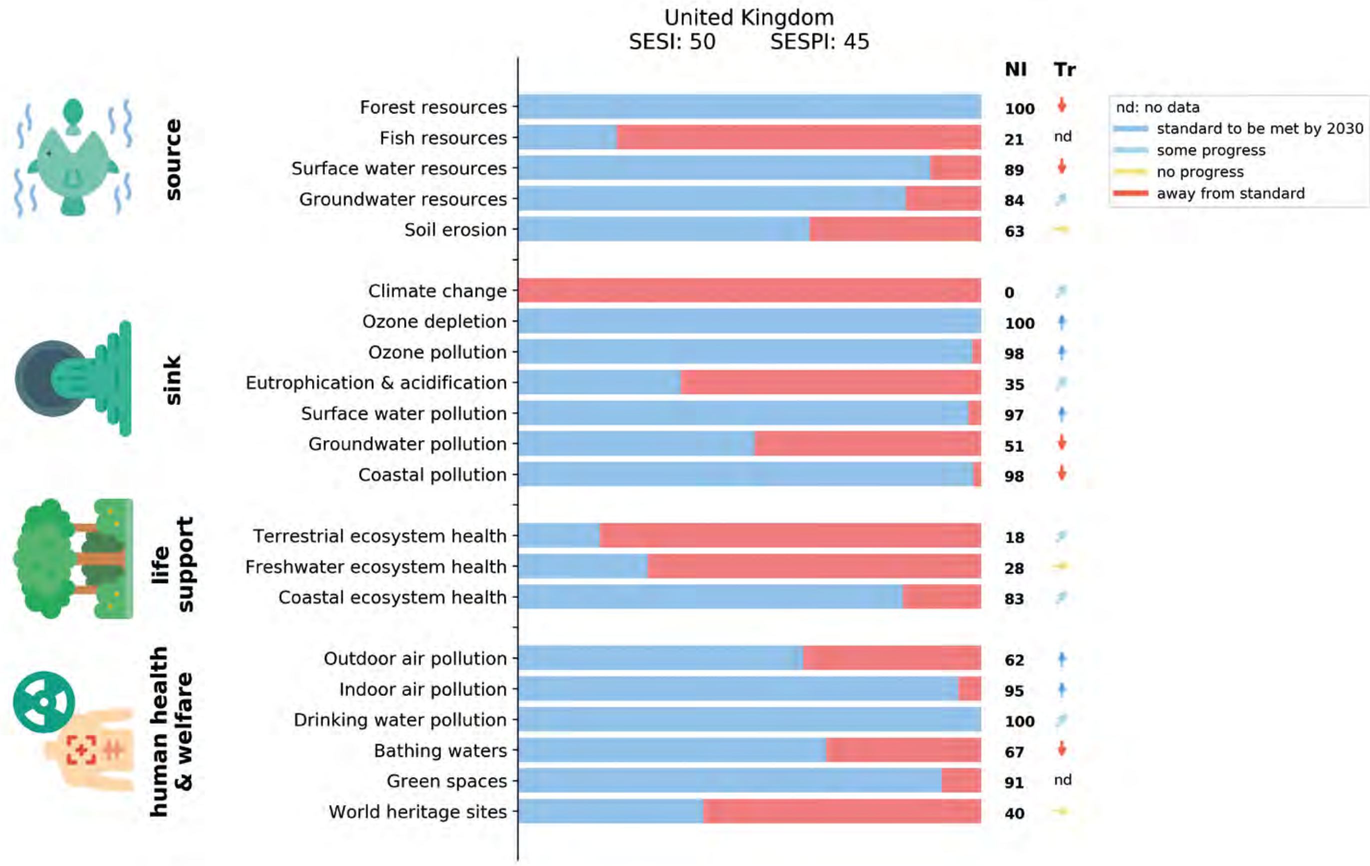
Having defined the principles and objectives of environmental sustainability, it is then necessary to specify the corresponding indicators and levels (called the scientific reference standards in the ESGAP framework) at which the environmental functions need to be maintained. Following review of the scientific literature, a set of indicators for which a scientific reference standard could be established was constructed (see **Table 2**), and the indicators normalised and aggregated into a single index, the Strong Environmental Sustainability Index (SESI). The SESI was calculated for 28 European countries, including the UK.[5-7]

By providing policy-makers with a clear picture of how far their country's current environmental performance is from the sustainable level indicated by the scientific reference standard, the SESI gives an overall picture of the distance to environmental sustainability. This is called the environmental sustainability gap. However, it may be that policy-makers wish to know whether the gap is closing or widening over time and whether on current trends the country's environmental performance will reach the scientific reference standard by a certain date. This is shown by the Strong Environmental Sustainability Progress Index (SESPI). This is constructed by comparing each indicator's linear trend between two dates for which there are data with the linear trend required to reach the scientific reference standard for that indicator by a certain date, and aggregating these comparisons into a single number.

TABLE 2. LIST OF INDICATORS IN THE STRONG ENVIRONMENTAL SUSTAINABILITY INDEX

FUNCTION	INDICATOR
Source	• Forest utilisation rate • Fish stocks within safe biological limits • Freshwater bodies not under water stress • Groundwater bodies in good quantitative status • Area with tolerable soil erosion
Sink	• Carbon dioxide emissions • Use of ozone-depleting substances • Cropland and forest area exposed to safe ozone levels • Terrestrial ecosystems not exceeding the critical loads of eutrophication and acidification • Surface water bodies in good chemical status • Groundwater bodies in good chemical status • Coastal water bodies in good chemical status
Life support	• Terrestrial habitats in favourable conservation status • Surface water bodies in good ecological status • Coastal water bodies in good ecological status
Human health and welfare	• Population exposed to safe levels of outdoor air pollutants • Population using clean fuels and technologies for cooking • Samples that meet drinking water criteria • Recreational water bodies in excellent status • Population with nearby green areas • Natural and mixed world heritage sites in good conservation outlook

(Source: Adapted from Usubiaga-Liaño and Ekins, 2021b[8])



Notes: NI = normalised indicator; Tr = trend

▲ **Figure 1. The Strong Environmental Sustainability Index and Strong Environmental Sustainability Progress Index calculations for the UK. (Source: Created from data in Usubiaga-Liaño and Ekins, 2021b, 2022[8,9])**

THE INDICES FOR 28 EUROPEAN COUNTRIES

The SESI and SESPI were calculated for 28 European countries, including the UK (see **Figure 1**).[9]

The blue portion of the bars (representing the indicators outlined in **Table 2**) shows the environmental performance on the date of calculation, while the red portion shows the distance to the scientific reference standard: the environmental sustainability gap. The normalised indicator (NI) column gives the score for each indicator (out of 100). Therefore, for the UK, the standard is met for forest resources, ozone depletion and drinking water pollution, and nearly met for tropospheric ozone pollution, surface water pollution and indoor air pollution. In contrast, there are very low scores for climate change – as greenhouse gas emissions are still very much above the scientific reference standard – and terrestrial and freshwater ecosystem health. The overall SESI score for the different reported years calculated is 50 (out of 100).

The trend (Tr) column is for the SESPI. Using the direction and colour of the arrows, this shows the trend calculated for each indicator to illustrate the movement towards or away from the standard and whether the standard will be met by 2030 (the chosen year, which corresponds to the SDGs' target date). Using linear projections (and with no implication that this is a forecast) the Tr column shows that the standard will be met by 2030 for ozone depletion, tropospheric ozone pollution, and indoor and outdoor air pollution; and that there is progress towards the standard for groundwater resources, climate change, eutrophication and acidification, and terrestrial and coastal ecosystem health, but not enough to meet it by 2030. The red downward arrows show a trend away from the standard.

CONCLUSION

The ESGAP framework has numerous features that together distinguish it from any other approach to indicators of environmental sustainability. Firstly, its basis in strong sustainability does not assume substitutability between the capital stocks that produce benefits for humans. It also shows that in respect of many environmental issues, particularly climate change and ecosystem health, performance falls short of sustainability. This is in line with the conclusions of natural scientists,

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who have identified a triple environmental crisis in respect of climate, nature and pollution.[10]

Secondly, its scoring of environmental performance with respect to scientific reference standards gives policy-makers something to aim for and an end state that signifies that environmental sustainability in respect of the SESI indicators has been reached. From there, environmental performance only needs to be maintained.

Thirdly, the indicators are formulated at the national level, at which most environmental policy is made and implemented, unlike the planetary boundaries. Lastly, and perhaps most importantly, the indicators allow policy-makers to identify the areas of worst environmental performance and where policy for improvement should be focused; at the same time, they summarise environmental performance overall (similar to how gross domestic product summarises national economic performance) and show overall progress towards environmental sustainability – unlike any other indicator framework.

These are important advantages of the ESGAP approach over other indicator frameworks. Hopefully they are powerful enough for the framework to be widely adopted. ES

Paul Ekins OBE is Professor of Resources and Environmental Policy at the Institute for Sustainable Resources at University College London. His academic work, published in 14 books, and over 200 articles and scientific papers, focuses on the conditions and policies for achieving an environmentally sustainable economy. His most recent book, published in 2024, is Stopping Climate Change: Policies for Real Zero. Paul received an OBE for services to environmental policy in 2015.

Arkaitz Usubiaga-Liaño is a postdoctoral researcher at the Basque Centre for Climate Change (BC3) in Spain. Prior to joining BC3, Arkaitz obtained his PhD at University College London and worked as a research fellow at the Wuppertal Institute for Climate, Environment and Energy in Germany. His research focuses on environmental indicators, with special emphasis on composite indices of environmental sustainability and carbon footprints.

REFERENCES

1. Inter-Agency and Expert Group on SDG Indicators (2016) *Final List of Proposed Sustainable Development Goal indicators.* https://sustainabledevelopment.un.org/content/documents/11803Official-List-of-Proposed-SDG-Indicators.pdf (Accessed: 28 April 2025).
2. Usubiaga-Liaño, A., Fairbrass, A. and Ekins, P. (2024) Strong sustainability and the environmental dimension of the Sustainable Development Goals. *Global Sustainability,* 7 (article: e52). doi:10.1017/sus.2024.47.
3. United Nations Environment Programme (2023) *Inclusive Wealth Report 2023: Measuring Sustainability and Equity.* https://wedocs.unep.org/handle/20.500.11822/43131 (Accessed: 28 April 2025).
4. World Bank (2024) *The Changing Wealth of Nations. Revisiting the Measurement of Comprehensive Wealth.* http://documents.worldbank.org/curated/en/099100824155021548 (Accessed: 28 April 2025).
5. Richardson, K., Steffen, W., Lucht, W. *et al.* (2023) Earth beyond six of nine planetary boundaries. *Science Advances*, 9 (37), article: eadh2458. https://doi.org/10.1126/sciadv.adh2458 (Accessed: 28 April 2025).
6. Usubiaga-Liaño, A. and Ekins, P. (2021a) Time for science-based national targets for environmental sustainability: an assessment of existing metrics and the ESGAP framework. *Frontiers in Environmental Science,* 9 (article: 761377). doi: 10.3389/fenvs.2021.761377.
7. Usubiaga-Liaño, A. and Ekins, P. (2024) Methodological choices for reflecting strong sustainability in composite indices. *Ecological Economics*, 221 (article: 108192). https://doi.org/10.1016/j.ecolecon.2024.108192 (Accessed: 28 April 2025).
8. Usubiaga-Liaño, A. and Ekins, P. (2021b) Monitoring the environmental sustainability of countries through the strong environmental sustainability index. *Ecological Indicators*, 132 (article: 108281). https://doi.org/10.1016/j.ecolind.2021.108281 (Accessed: 28 April 2025).
9. Usubiaga-Liaño, A. and Ekins, P. (2022) Are we on the right path? Measuring progress towards environmental sustainability in European countries. *Sustainability Science*, 18, pp. 755–770. https://doi.org/10.1007/s11625-022-01167-2 (Accessed: 28 April 2025).
10. United Nations Climate Change (2022) *What is the triple planetary crisis?* https://unfccc.int/news/what-is-the-triple-planetary-crisis (Accessed: 28 April 2025).

ANALYSIS

Pesticide environmental indicators and the need to minimise uncertainty

Kathy Lewis and **John Tzilivakis** discuss the complexities of data choices and availability when assessing progress towards meeting objectives.

Environmental indicators are invaluable for assessing the progress made over time towards environmental objectives. They provide insight into specific aspects of either the environment or human health and are used extensively in policy to establish priorities, evaluate implementation and assess compliance with international commitments. However, indicators are a substantial simplification of reality and have faced significant criticism for not accounting for uncertainties, as well as for their often arbitrary nature. Uncertainties are often unavoidable and arise from the natural data variation, data gaps and inherent assumptions made in data generation and selection. While some of these issues can be overcome by using more complex environmental models and sophisticated environmental impact methodologies, a common issue related to the acquisition of quality data remains.

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This issue can be clearly illustrated with pesticide indicators. Pesticides play a significant role in delivering good-quality, plentiful food – and food security more generally – but are also associated with potential risks to human health, biodiversity and the wider environment. Therefore, a key challenge for policy-makers and other stakeholders is the development of tools to adequately characterise these risks and to support the development of sound, evidence-based policies. Over the last two decades numerous pesticide indicators have been developed for this purpose and tend to be used as a proxy measure of environmental risk. Some of the simplest are based on the quantity of an active substance used, while others are more complex, composite indicators that attempt to combine usage information with chemical data related to environmental fate, transport and (eco)toxicity.[1-3]

COMMONLY USED PESTICIDE INDICATORS

One of the more successful composite indicators is the Danish pesticide load indicator (PLI).[4,5] Within this, a pesticide load is calculated for three sub-indicators (human health, environmental fate and ecotoxicity) based on scores allocated to specific fate and (eco)toxicological parameters within each sub-indicator and expressed as the load per unit of commercial product (e.g. litre, kilogram, standard dose).

More recently, the Danish PLI has been amended to better suit the needs of the UK.[6,7] The UK PLI consists of 16 ecotoxicity and four fate metrics (which are not aggregated) and is now being used as the basis of a national target to reduce pesticide load by at least 10 per cent between 2018 and 2030.[8]

Other frequently used composite indicators include the environmental impact quotient (EIQ), which has been developed to provide growers with data regarding the environmental and health impacts of pesticide options so they can make better-informed decisions.[9] The pesticide occupational and environmental risk (POCER) indicator, based on Annex VI of European Directive 91/414/EC, is also well established and considers the risk arising from occupational, non-dietary exposure and the risk to the environment.[10,11] More recently the total applied toxicity (TAT) indictor and its associated aggregated version (ATAT) have emerged.[12,13] The TAT is similar to the PLI, integrating the total amount of applied pesticides, weighted by a measure of their individual (eco)toxicities.

DATA AVAILABILITY

All these types of indicators rely on large amounts of data related to, for example, the amount applied, the physico-chemical properties of the pesticide, descriptors of how the pesticide disperses in the environment, and its toxicity to humans and biodiversity. The latter may cover multiple terrestrial and aquatic species. An indicator for a single pesticide may need 15 or more different parameters. The problem is that not only are there hundreds of different pesticides in active use globally (each having a unique dataset) but also that the data are scattered across numerous online and offline resources and are inherently variable in nature – for example, ecotoxicity data will vary according to species, sub-species, gender and life stage.

Indicators and risk assessment approaches are constantly developing and expanding with respect to the data needed, and new data are constantly being generated. Therefore, it is imperative that data resources are regularly maintained. However, few of the available resources are actively maintained and updated. There are often significant data gaps to be managed, and data quality is not always known. Consequently, uncertainty can be very significant and if not properly understood and managed can lead to flawed decision-making. As uncertainty is almost impossible to avoid completely – all indicators are simplifications of reality – it is important to understand and minimise additional uncertainty introduced from the data used in their calculation.

Regardless of what form the composite indicator takes, data on the quantity of pesticide applied in each country will be needed. The availability of these data is inherently down to national policy and priorities. Some countries have strict reporting requirements – for example, Denmark, Japan, the USA and Australia – while others use a survey approach, such as the UK, Canada and New Zealand, and apply statistical techniques to provide estimates of national usage. Some countries have no reporting requirements (e.g. India, Brazil and Nigeria) and so might use pesticide sales as a surrogate for usage. Consequently, there will be inherent and potentially significant uncertainty in usage data. While it is possible to determine uncertainty in the statistical estimation of national usage, as is done in the UK PLI, there is rarely much potential to improve usage data availability, especially in the short term and without policy impetus.

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Inevitably, each indicator and each application thereof uses a unique dataset comprising various, often undisclosed sources. If the indicator is applied in an identical manner, temporally, for a specific country or study, then the uncertainty will remain relatively constant; as such, it will not be a significant issue, provided it is interpreted appropriately. However, there are various ongoing activities where such indicators are being proposed for monitoring, comparing and contrasting pesticide use internationally, and so there is potential for different countries to collate and manage data differently.

AGGREGATED TOTAL APPLIED TOXICITY

As an example, it is currently anticipated that the ATAT will be used as the Headline Indicator 7.2 currently being developed for the monitoring framework of the Kunming–Montreal Global Biodiversity Framework for the Convention on Biological Diversity. This headline indicator aims to measure the potential risk posed by pesticides to biodiversity. It is part of a suite of 26 headline indicators in the Convention and, more specifically, it addresses Target 7: 'To reduce pollution risks and the negative impact of pollution from all sources by 2030, to levels that are not harmful to biodiversity, and ecosystem functions and services'.[14] It has an overall commitment to achieve a 50 per cent reduction in pesticide use globally by 2030 based on the ATAT. The intention is that each country applies the indicator to calculate and report the national value back to the United Nations for comparison and monitoring purposes.

The ATAT uses regulatory threshold level (RTL) values as a measure of ecotoxicity. A pesticide RTL is an exposure level above which adverse effects are observed in (eco)toxicological studies, and below which adverse effects are not expected to occur. In other words, the worst-case ecotoxicity value for a particular species group (e.g. fish, birds, terrestrial arthropods) is used. Ideally, this would be a chronic toxicity threshold such as the no observed effect level (NOEL) or no observed effect concentration (NOEC), but often these data are not available so acute toxicity data (e.g. median lethal dose measures: LC_{50}, LD_{50}, ER_{50}) are used together with a (somewhat arbitrary) safety or conversion factor.

There is no single data source for RTLs with regulatory authorities, and researchers create their own datasets using various data sources and methodologies (including experimental activities and mathematical modelling) to establish these thresholds. There is little doubt that this introduces significant uncertainty. Firstly, each dataset is likely to be very different and potentially not reproducible by third parties. Secondly, it is very difficult, if not impossible, to know when the worst-case value has been identified (i.e. when do you stop the data search?). There is no clear definition of what species (or sub-species) make up a particular biodiversity group. For example, in a study that applied the TAT to German agriculture, ten different fish species were used but their precise identification is not given.[12]

This uncertainty within the ATAT is addressed by the introduction of another factor to provide a safety margin. Within the ATAT pesticide use data may be derived from a range of sources including farmer or producer reports to governments, pesticide sales, trade information (import/export) or national crop production data. Therefore, there is considerable scope for additional uncertainty. This presents challenges as an approach for comparing data on an international basis.

The PLI (Danish and UK) along with other composite indicators such as POCER, SYNOPS (synoptic assessment of plant protection products) and the EIQ take a different approach.[1,15,16] Instead of using RTLs they utilise a suite of indicator species identified for regulatory purposes from experimental work. These species are selected as being particularly sensitive to environmental pollution and because they can represent their broader ecological group. For example, the indicator species for fish are rainbow trout (*Oncorhynchus mykiss*) and bluegill sunfish (*Lepomis macrochirus*). The selected ecotoxicity endpoint used would be the lowest for these species. While it may be that risk is, in some rare instances, underestimated, the data are much more transparent and more readily available. This approach allows for consistency and comparability across different studies and assessments where the same indicator methodology is applied.

The need, therefore, especially where the indicator is used for meeting international commitments, is for a single, readily available, comprehensive, managed source of the data to be used regardless of the indicator chosen. One solution used by the most common composite indicators is the pesticide properties database (PPDB).[17,18] This has been available since 1996 in various formats and as an online free-to-use resource since 2006. More recently, a variety of new parameters, data sources and improvements in functionality have contributed to the growth and utility of the resource.

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The database uses a rule-based system to source and present the best-available data, and it is continuously updated and expanded. It is endorsed by the International Union of Pure and Applied Chemistry and the Food and Agriculture Organization, and it is now the most significant and comprehensive data resource worldwide, providing a consistent source of quality, peer-reviewed data.

FINDING GLOBAL DATASET CONSENSUS

We live in an information age that is driven by data, and the interpretations of that data paint the pictures on which decisions are based. When painting these pictures, if we use different datasets and methods we risk having different pictures of the same thing, resulting in barriers to consensus and, in a worst-case scenario, making the wrong decisions.

In the context of understanding and assessing the environmental impacts of pesticide use, there needs to be agreement on the most appropriate and reliable methods for the context at hand; and these methods need to be underpinned by common, curated datasets. The key word here is 'curated', where the governance of the dataset is transparent and independent. If there can be global agreement on what data should be used for common metrics, then this can be made available via multiple sources (e.g. the PPDB) to those who need them. Without this, we risk a free-for-all, where everyone either cobbles together their own datasets and the metrics that emerge cannot be compared, or we end up with a patchy, inconsistent and ultimately unreliable global picture. ES

Professor Kathy Lewis, BSc PhD FIAP MIEMA, is Professor of Agricultural Chemistry and Director of the Agriculture and Environment Research Unit (AERU), which is based at the University of Hertfordshire. Kathy has over 30 years of experience related to environmental chemistry, food and agri-environmental systems, environmental impact and risk assessments particularly for policy applications. Recently, her research has concentrated on areas related to regulatory risk assessment of pollutants in the environment, which includes development of various models and decision support systems, considering environmental fate, transport, exposure and ecotoxicology, based on regulatory approaches.

Dr John Tzilivakis, BSc MSc PhD PIEMA MIAP, is a Reader in Agricultural and Environmental Systems at AERU. He has over 25 years of experience associated with agri-environmental indicators and evaluations, principally for policy development and support, especially those related to agricultural pollution (nutrients and pesticides), and the impacts of agricultural production on agroecology and climate change.

REFERENCES

1. Meys, E.L., Mineau, P., Werts, P. *et al.* (2024) Assessment of insecticide risk quantification methods: introducing the pesticide risk tool and its improvements over the environmental impact quotient. *Journal of Integrated Pest Management,* 15 (1), p. 9. https://doi.org/10.1093/jipm/pmad032 (Accessed: 28 April 2025).
2. Rainford, J., Kennedy, M. and Jones, G. (2021) *Pesticide Risk Indices: A Review of Practical Implications for Policy and Interpretation.* https://voluntaryinitiative.org.uk/media/o55fry2j/pesticide-risk-indices-a-review-of-practi-cal-implications-for-policy-and.pdf (Accessed: 28 April 2025).
3. Möhring, N., Bozzola, M., Hirsch, S. and Finger, R. (2020) Are pesticides risk decreasing? The relevance of pesticide indicator choice in empirical analysis. *Agricultural Economics*, 51 (3), pp. 429–444. https://doi.org/10.1111/agec.12563 (Accessed: 28 April 2025).
4. Kudsk, P., Jørgensen, L.N. and Ørum, J.E. (2018) Pesticide load – a new Danish pesticide risk indicator with multiple applications. *Land Use Policy*, 70, pp. 384–393. https://doi.org/10.1016/j.landusepol.2017.11.010 (Accessed: 28 April 2025).
5. Miljøstyrelsen (2012) *The Agricultural Pesticide Load in Denmark 2007–2010.* Environmental review no.2. https://www2.mst.dk/Udgiv/publikationer/2012/03/978-87-92779-96-0.pdf (Accessed: 28 April 2025).
6. Kennedy, M., Garthwaite, D., Ridley, L. and Tzilivakis, J. (2024) *UK Pesticide Load Indicator. Phase 5 Update Report.* Prepared for the Department for Environment, Food and Rural Affairs. https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectId=21394 (Accessed: 28 April 2025).
7. Lewis, K., Rainford, J., Tzilivakis, J. and Garthwaite, D. (2021) Application of the Danish pesticide load indicator to arable agriculture in the UK. *Journal of Environmental Quality*, 50 (5), pp. 1110–1122. https://doi.org/10.1002/jeq2.20262 (Accessed: 28 April 2025).
8. Department for Environment, Food & Rural Affairs, Welsh Government, The Scottish Government, and Northern Ireland Executive (2025) *UK Pesticides National Action Plan 2025.* Policy paper. https://www.gov.uk/government/publications/uk-pesticides-national-action-plan-2025 (Accessed: 28 April 2025).
9. Messer, L.C., Jagai, J.S., Rappazzo, K.M. and Lobdell, D.T. (2014) Construction of an environmental quality index for public health research. *Environmental Health*, 13 (article: 39), pp. 1–22. https://doi.org/10.1186/1476-069X-13-39 (Accessed: 28 April 2025).
10. Council Directive 91/414/EEC of 15 July 1991 concerning the placing of plant protection products on the market. https://eur-lex.europa.eu/eli/dir/1991/414/oj/eng (Accessed: 30 April 2025).
11. Mullen, J.D. and Rubin, M.K. (2024) A rapid assessment technique for identifying future water use and pesticide risks due to changing cropping patterns. *Sustainability*, 16 (11), article: 4853. DOI:10.3390/su16114853.
12. Bub, S., Wolfram, J., Petschick, L.L. *et al.* (2022) Trends of total applied pesticide toxicity in German agriculture. *Environmental Science & Technology*, 57 (1), pp. 852–861. https://doi.org/10.1021/acs.est.2c07251 (Accessed: 28 April 2025).
13. United Nations Environment Programme World Conservation Monitoring Centre (2024) *Aggregated total applied toxicity (ATAT).* Metadata factsheet. https://gbf-indicators.org/metadata/headline/7-2 (Accessed: 28 April 2025).
14. United Nations Environment Programme Convention on Biological Diversity (no date) *Kunming–Montreal Global Biological Framework Target 7. Reduce pollution to levels that are not harmful to biodiversity.* https://www.cbd.int/gbf/targets/7 (Accessed: 5 May 2025).
15. Fishkis, O., Strassemeyer, J., Pöllinger, F. *et al.* (2024) Toxicological risk assessment of mechanical-chemical vs. chemical weed control techniques in sugar beet in Germany using SYNOPS-GIS. *Frontiers in Agronomy,* 5, (article: 1274703). https://www.frontiersin.org/journals/agronomy/articles/10.3389/fagro.2023.1274703/pdf (Accessed: 28 April 2025).
16. Dugan, S.T., Muhammetoglu, A. and Uslu, A. (2023) A combined approach for the estimation of groundwater leaching potential and environmental impacts of pesticides for agricultural lands. *Science of the Total Environment,* 901, (article: 165892). https://doi.org/10.1016/j.scitotenv.2023.165892 (Accessed: 28 April 2025).
17. University of Hertfordshire (no date) *PPDB: pesticide properties database.* https://sitem.herts.ac.uk/aeru/ppdb/ (Accessed: 28 April 2025).
18. Lewis, K.A., Tzilivakis, J., Warner, D.J. and Green, A. (2016) An international database for pesticide risk assessments and management. *Human and Ecological Risk Assessment: An International Journal*, 22 (4), pp. 1050–1064. https://doi.org/10.1080/10807039.2015.1133242 (Accessed: 28 April 2025).

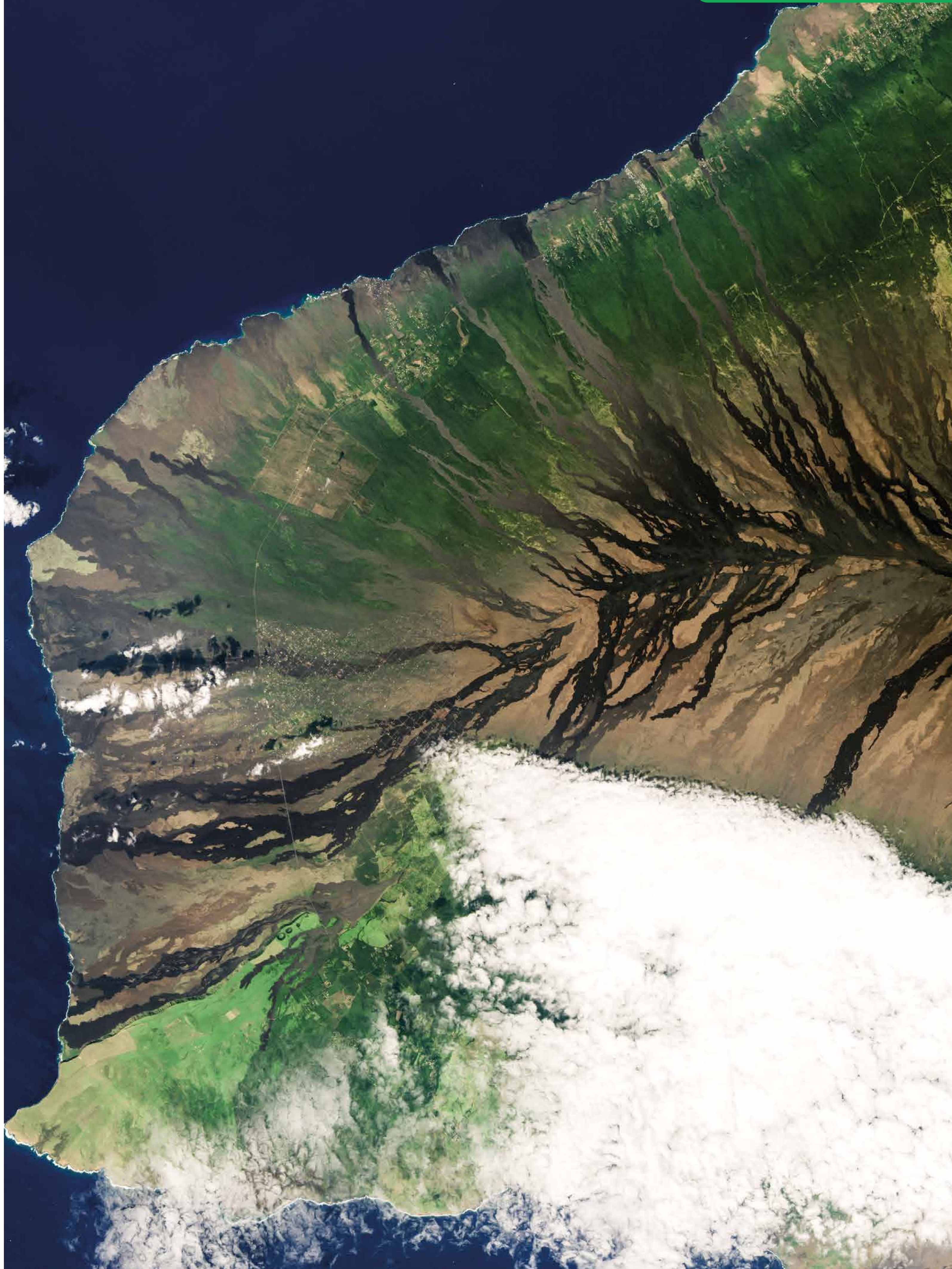
Indicators for environmental monitoring and assessment: current state and future challenges

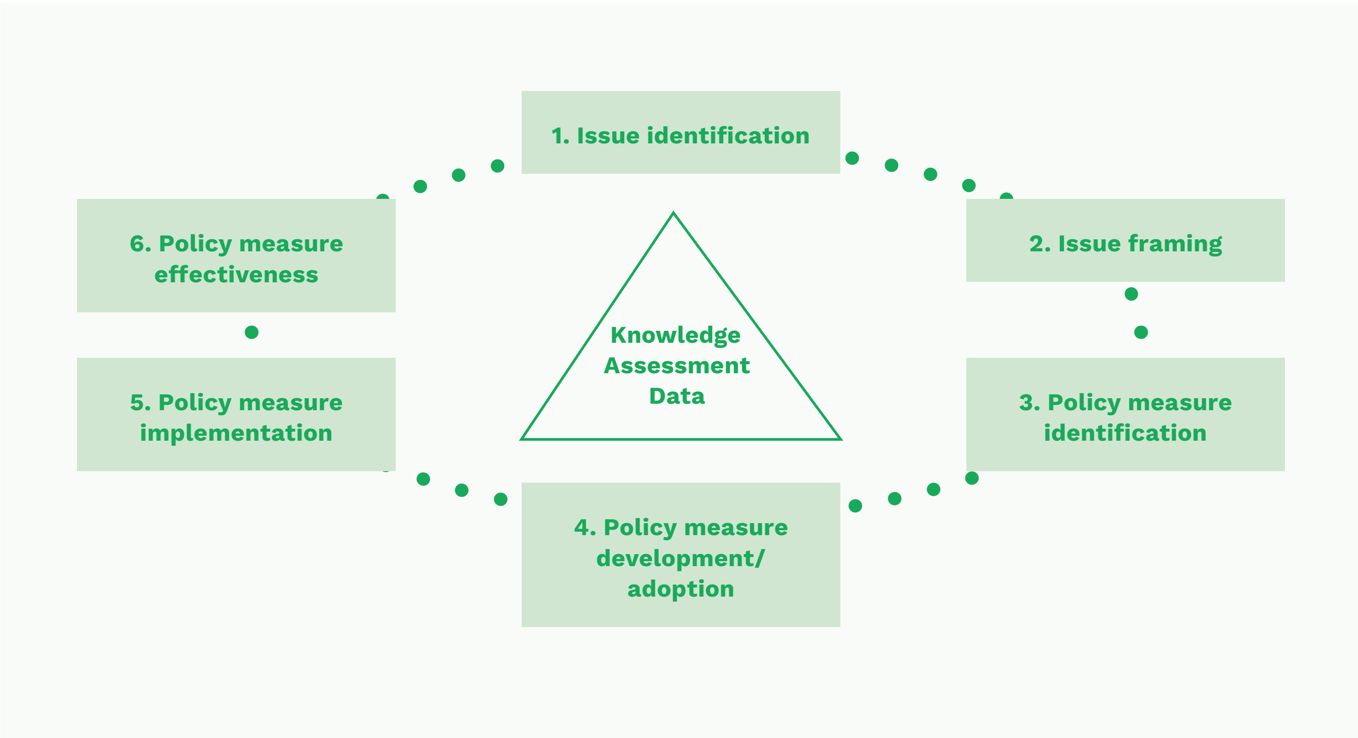
Cathy Maguire examines the role of environmental indicators in policy and decision-making.

Environmental indicators provide selected, aggregated and interpreted information. They reduce the number of measurements or parameters that would normally be required to represent an issue, and they simplify the way in which complex matters can be communicated. For example, the trend in the amount of carbon dioxide being emitted to the atmosphere is used to illustrate the much more complex realities of climate change.

▶ Mauna Loa island, Hawaii, where the concentration of atmospheric CO_2 is measured. © Blue | Adobe Stock

OPINION





▲ **Figure 1. The policy cycle. (Adapted from European Environment Agency, 2014[1])**

This makes indicators essential tools in supporting policy and decision-making and they are commonly used across the different stages of the policy cycle (see **Figure 1**). Indicators provide information on the state of and trends in the environment as well as information on environmental problems. This supports policy development and priority setting by enabling policy-makers to target interventions at activities causing pressures on the environment and at key factors that influence environmental outcomes. Indicators that correspond to specific policy areas, targets and objectives are used to monitor policy progress, which informs implementation and evaluation of the effectiveness of policy responses.

Indicators are commonly combined to form a set, where each indicator is presented individually and provides one part of the picture. This enables indicator sets to encompass different dimensions of an issue or policy area without losing information through aggregation, making them useful for analysis. Individual indicators can also be used to develop composite indicators and indices where they are aggregated into one measure. This approach is often used for multidimensional concepts that cannot be captured using a single indicator.

Aggregated indices often have stronger communication than analytical value, but when a time series is available, the direction of the trend can be informative at a strategic level. Therefore, each has different strengths and weaknesses, so the most suitable indicator will depend on the intended use.

HOW ENVIRONMENTAL INDICATORS ARE USED

The Office for Environmental Protection (OEP) assesses progress in improving the natural environment in line with Environmental Improvement Plans (EIPs) and the Environment Act 2021 targets in England and Northern Ireland. Providing an independent assessment of progress is important to enable scrutiny of government's performance and how it can be improved. This contributes to efforts to ensure that government achieves the significant environmental improvements that it has committed to and that are so urgently needed.

The OEP's EIP progress assessment is based on available knowledge, evidence and analysis. An integrated assessment approach is used to analyse issues within and across environmental domains, across geographical scales, and over past, present and future timescales. The assessment draws on a wide range of evidence

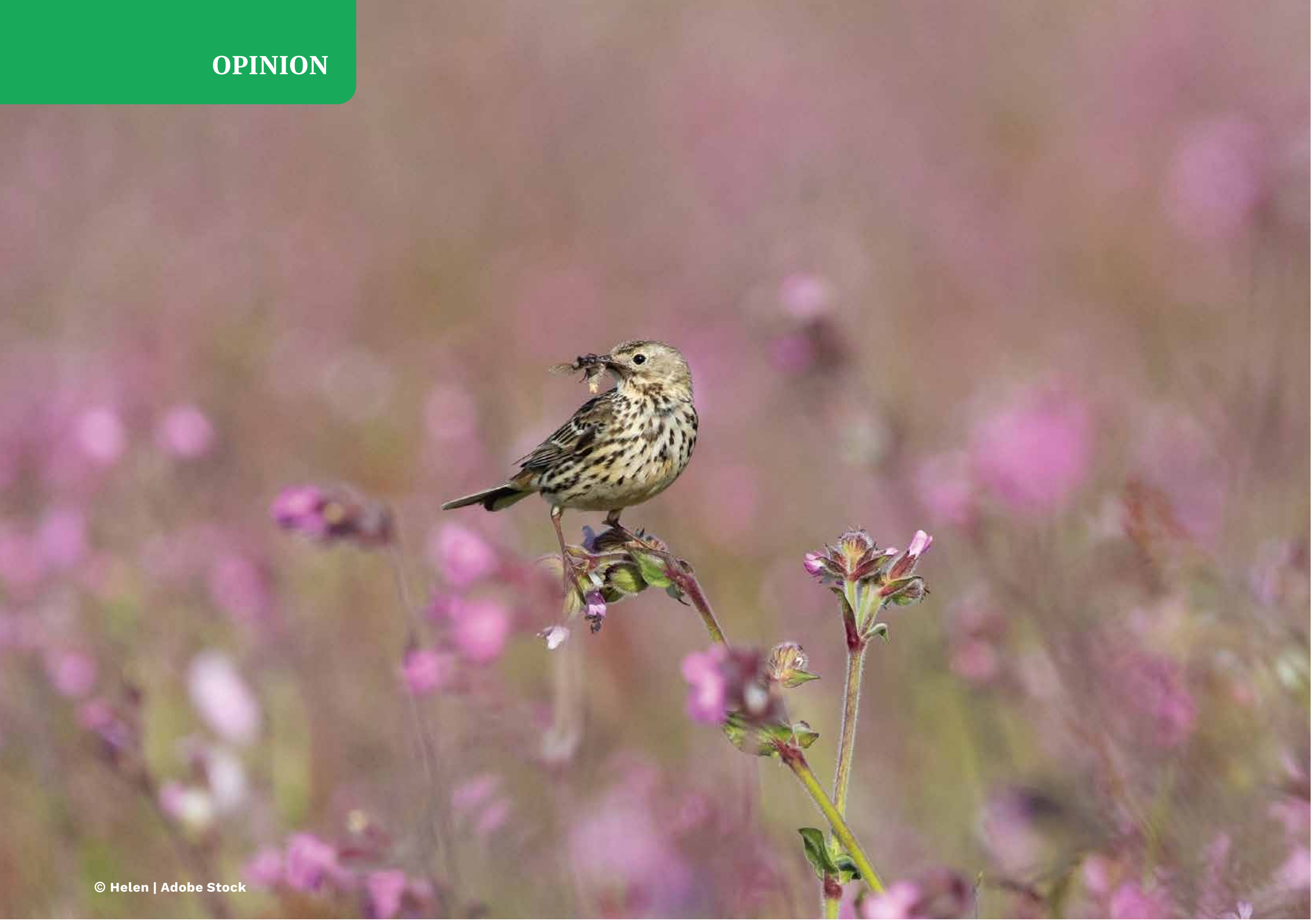
ICON	TREND CATEGORY	TREND DIRECTION	ASSESSMENT OF CHANGE
	Improvement	Increasing	Positive developments more prevalent
	Improvement	Decreasing	Negative developments less prevalent
	Little or no change	No change	No change for better or worse
	Deterioration	Increasing	Negative developments more prevalent
	Deterioration	Decreasing	Positive developments less prevalent
	Not assessed	Single data point or time series too short to adequately assess progress	Only the current state can be evaluated
	Not assessed	No appropriate data to assess progress	Represents a major data gap

▲ **Figure 2. Indicator trend assessment categories. (Source: Office for Environmental Protection, 2025[5])**

including a set of environmental indicators. The indicator set needs to cover the broad scope of the EIP, so a policy-driven approach to selection is used rather than a conceptual framework. Selection criteria ensure that the indicators relate to key aspects of the environment, make intuitive sense to a wide range of users, and enable assessment of progress towards key targets and commitments.[2]

Where possible, indicators from Defra's Outcome Indicator Framework are used, as this aims to provide a set of indicators that relate to all aspects of the environment and how it is changing.[3] However, while the indicator set used in the EIP progress assessment is broad, it does not capture all its aspects, so it can only ever provide a partial picture. There are also challenges in identifying indicators that directly relate to specific targets and commitments, along with key data gaps and issues with timeliness of data.

To summarise change in environmental trends and whether it constitutes improvement or deterioration, a red–amber–green symbol and directed arrows are used (see **Figure 2**). The arrows indicate the direction of change, and so improvement can be illustrated by a downward (e.g. a decrease in the emission of air pollutants) or an upward arrow (e.g. increased tree cover). Where an assessment is not possible due to the lack of a time series, a grey circle is used, and where data are not available, a grey cross. In general, change is assessed over a five-year period and the percentage increase or decrease uses a 3 per cent threshold, with any variation from this approach specified in the methodological statement that accompanies each EIP progress assessment.[4]



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The OEP's latest assessment used a set of 55 indicators to analyse 59 trends across the EIP's 10 goal areas.[5] This aimed to answer the question of whether England's natural environment is improving. While there are signs that the downward trajectory in England's species abundance is slowing, wider biodiversity trends continue to deteriorate and some pressures on biodiversity have not decreased. The overall state of the water environment remains challenging with deteriorating trends observed in the marine environment.

However, when it comes to reducing overall levels of pollution, there are improving trends regarding reductions in specific air pollutants (e.g. particulate matter such as $PM_{2.5}$), specific chemicals (e.g. mercury and polychlorinated biphenyls, better known as PCBs) and greenhouse gases (e.g. hydrofluorocarbons, known as HFCs). Trends in patterns of production and consumption are mixed. While resource productivity has improved, resource use is increasing and there has been little change in England's carbon footprint. And while residual waste generation has stabilised, recycling rates have stalled.

In relation to human health and well-being, improving trends dominate for air quality although some standards are still being exceeded. In terms of engagement with the natural environment, while the frequency of adults' visits to the natural environment and levels of pro-environmental behaviour both showed little or no change, deteriorating trends were observed for children.

As the EIP progress assessment is quite comprehensive, summary assessments are used to present the analysis in a concise and accessible way and to provide an overview of trends across the 10 goal areas (see **Figure 3**).

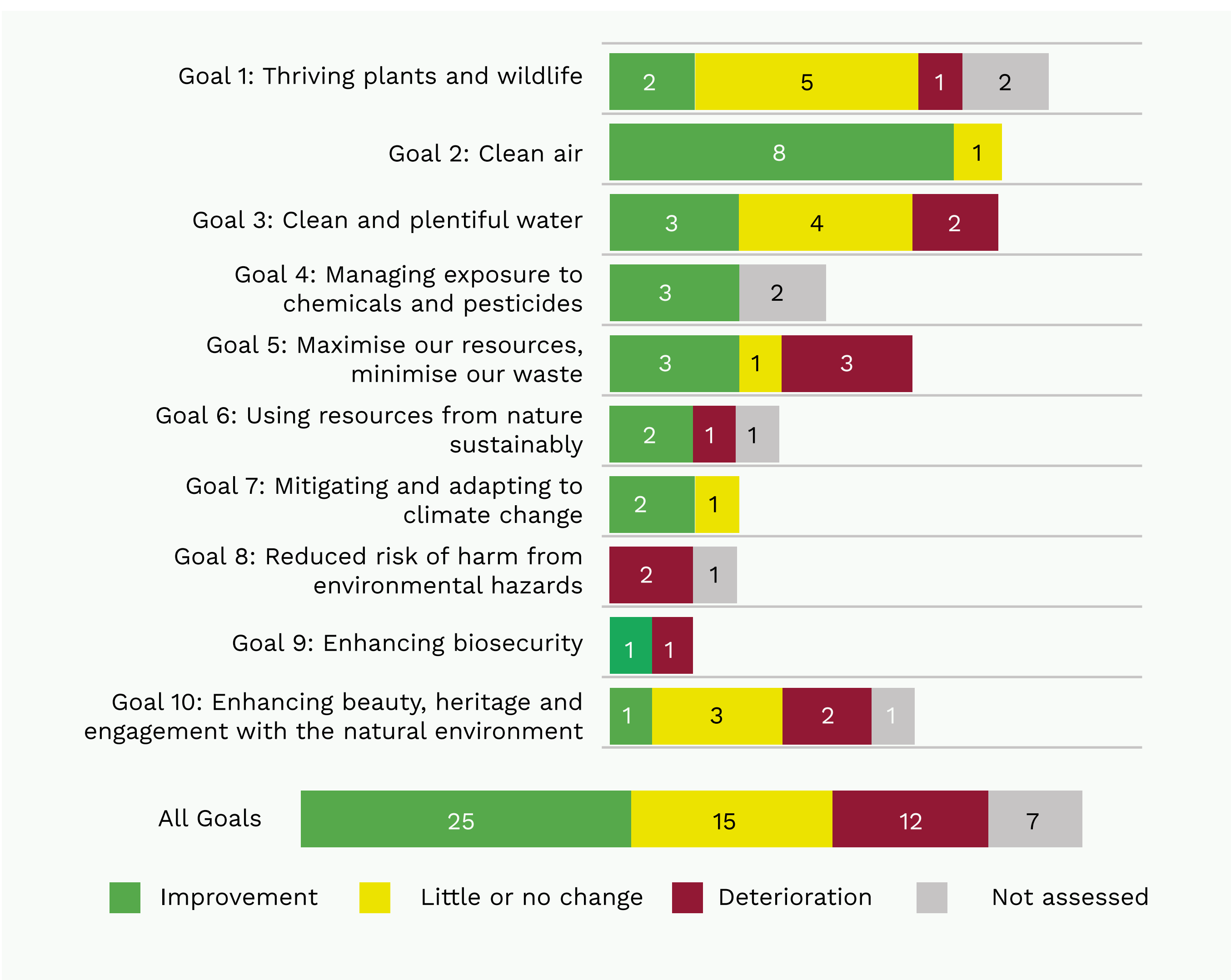
The indicator-based analysis of environmental trends also informs the assessment of recent progress towards meeting ambitions, targets and commitments as well as the prospects of meeting them. The analysis of environmental trends demonstrated that there is more success in addressing specific environmental problems, particularly pollutants, with targeted instruments than more complex or systemic environmental challenges. While indicators can illustrate and substantiate statements made in the assessment, particularly where they provide information on

specific targets or reference values, it is also necessary to put them into the context of a wider evidence base to fully assess progress and prospects.

INDICATOR DEVELOPMENT AND ITS CHALLENGES

Indicators published by government for environmental monitoring have mainly been developed in response to policy priorities, legislative requirements and assessment demands. Indicators developed in the 1980s and early 1990s tend to relate to well-established issues such as air and water pollution, waste generation and nature conservation. The 1990s saw the development of indicators focused on the integration of environmental considerations into sectors with the greatest environmental impacts such as agriculture, energy, industry and transport. Since then there has been demand for indicators for more complex and systemic challenges such as climate change, biodiversity loss, ecosystem resilience, and the effects of environmental degradation on human health and well-being.

In recent publications, the IES set out challenges related to evidence-informed policy-making and knowledge needs in a world of transformative change.[6,7] These include the need for evidence that helps us understand the world and what we know about it. For indicators, this means ensuring that the most appropriate ones are developed and that they measure whether interventions are making a difference in order to inform decisions and adaptative management.



▲ **Figure 3. Summary of the Office for Environmental Protection's assessment of 59 trends across 55 environmental indicators in the 10 goal areas of the Environmental Improvement Plans. (Source: Office for Environmental Protection, 2025[5])**

Environmental outcomes are determined by a wide range of factors and most environmental pressures are linked to the systems that meet society's needs for food, energy, mobility and the built environment. As a result, these drivers of environmental degradation and nature loss are tied in complex ways to jobs and earnings; to infrastructure investments, skills and knowledge; and to lifestyles, public policies and institutions. Persistent environmental and climate problems cannot be fully resolved without addressing broader sustainability issues and considering the environmental, social, economic and governance dimensions of human activities.[8]

This means that in addition to current indicators there is a clear need to develop indicators that enable better understanding of environmental, economic and societal interactions as well as coherence, synergies and trade-offs to inform effective policy interventions. Accounting approaches enable the production of a time series of consistent, comparable and coherent statistics and indicators. The System of Environmental-Economic Accounting integrates economic and environmental data, and measures environmental assets and their benefits to society to generate a range of indicators with different potential analytical applications.[9] Integration across accounting modules, though complex, can deliver benefits by furthering the understanding of environmental, economic and societal interactions.

However, the time involved in developing new indicators and establishing their use in policy and decision-making means that a common response to meeting new demands is to revisit existing indicators to see how they can be used. This sometimes includes further development of established indicators, even those with regular monitoring and reporting regimes, to try to improve timeliness by using real-time data, early estimates and nowcasting.

While indicators usually report past developments and provide historical time series, they can also be used to explore potential futures and to model the impact of policy options. However, unless the indicator directly captures the relevant policy outcome or measures the same parameter as a target, it will not provide information on whether these are likely to be met or to determine the gap between the current situation and the desired outcome. In addition, while indicators can demonstrate change, they will not necessarily provide information on the reasons why; and so, there will always be a degree of uncertainty regarding the impact of interventions, and indicators will always need to be used in combination with other quantitative and qualitative evidence and expert judgement in assessments.

In addition to those indicators published by government, there are also many indicator frameworks and indicators generated by research projects; however, these are often neither replicated nor produced regularly. Who produces indicators matters in determining their uptake so, even if promising, it can be a challenge to get new indicators or approaches institutionalised and embedded within a monitoring or assessment process. This is illustrated by the time it has taken from the initial development of environmental footprints as research outputs to their regular production today by national statistical offices.

Looking ahead, today's complex and systemic environmental challenges also require indicators that provide a better picture of what is happening with key leverage points, signals of change, barriers and enablers as well as transformation processes. However, the ultimate goal is to provide insights and evidence that lead to action. This requires thinking about indicator development from different perspectives. While it is essential to look at what data are available, how they can be used more effectively and what is needed, it is also essential to place this into the context of a compelling narrative for action and an understanding of how people respond to and engage with information. Bringing together these different perspectives is what integrated assessment does: take available evidence and place it within a narrative that joins the dots and links to policy.

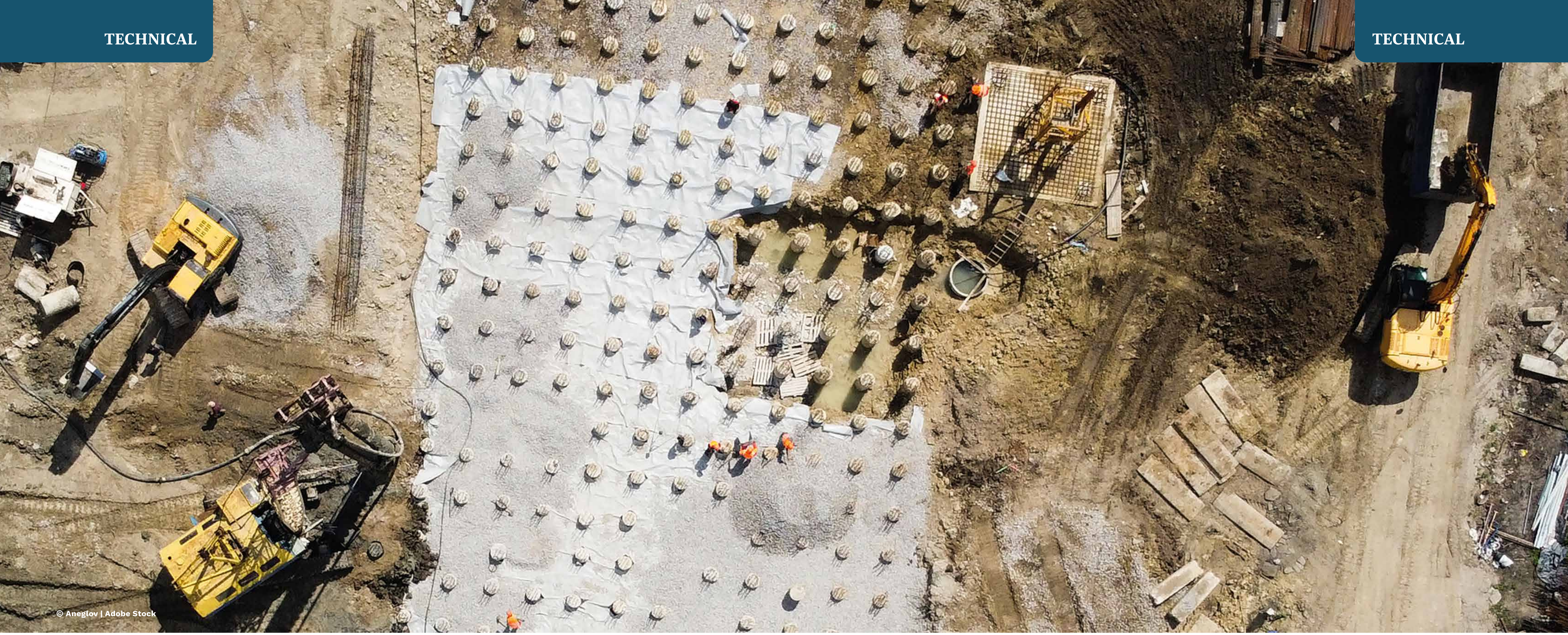
The indicator set used by the OEP to analyse trends in the natural environment will always need to reflect the scope and content of government's EIP and have a strong focus on the state, pressures and impacts on the environment. However, the EIP progress assessment also includes identifying opportunities for improvement. So while they may not be used in a trend assessment, a broader set of indicators will strengthen understanding of effective interventions to inform policy and decision-making so it results in environmental improvement and a more sustainable future. ES

Cathy Maguire is Head of Assessments at the OEP where she leads its work monitoring, assessing and reporting on government progress in improving the natural environment in line with its EIPs, goals and targets. She is also an Honorary Professor of Practice at Queens University Belfast.

REFERENCES

1. European Environment Agency (2014) *Digest of EEA Indicators 2014.* EEA Technical Report No. 8/2014. https://www.eea.europa.eu/en/analysis/publications/digest-of-eea-indicators-2014/digest-of-eea-indicators-2014/@@download/file (Accessed: 2 June 2025).
2. Office for Environmental Protection (2024) *Methodological Statement – Progress in Improving the Natural Environment in England 2022/2023.* https://www.theoep.org.uk/sites/default/files/reports-files/E02987560_Un-Act%20Monitoring%20Progress%20with%20the%20EIP_Methodological%20Statement_Accessible.pdf (Accessed: 2 June 2025).
3. Department for Environment, Food & Rural Affairs (no date) *Outcome Indicator Framework.* https://oifdata.defra.gov.uk/outcome-indicator-framework/ (Accessed: 31 May 2025).
4. Office for Environmental Protection (2025) *Methodological Statement – Progress in Improving the Natural Environment in England 2023/2024.* https://www.theoep.org.uk/sites/default/files/reports-files/Methodological%20Statement%20-%20Progress%20in%20improving%20the%20natural%20environment%20in%20England%202023-2024.pdf (Accessed: 31 May 2025).
5. Office for Environmental Protection (2025) *Progress in Improving the Natural Environment in England 2023/2024.* https://www.theoep.org.uk/sites/default/files/reports-files/Progress%20in%20improving%20the%20natural%20environment%20in%20England%202023-2024.pdf (Accessed: 31 May 2025).
6. The Institution of Environmental Sciences (2025) *An Evidence-Informed Environment.* https://www.the-ies.org/sites/default/files/reports/an_evidenceinformed_environment_report_0.pdf (Accessed: 31 May 2025).
7. The Institution of Environmental Sciences (2025) *Knowledge in a World of Transformative Change.* https://www.the-ies.org/sites/default/files/reports/knowledge_in_a_world_of_transformative_change.pdf (Accessed: 31 May 2025).
8. European Environment Agency (2020) *The European Environment – State and Outlook 2020: Knowledge for Transition to a Sustainable Europe.* https://www.eea.europa.eu/en/analysis/publications/soer-2020/soer-2020/@@download/file (Accessed: 31 May 2025).
9. United Nations (no date) *System of environmental economic accounting.* https://seea.un.org/ (Accessed: 31 May 2025).

TECHNICAL



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The pH parameter in water at construction and electrical infrastructure sites

Craig Speed addresses its scale, nature, occurrence and the myths associated with it.

We think of pH as a simple measure of acidity or alkalinity. But is that all it is? Of all the chemical parameters in water monitoring, pH is a little more complicated and prone to misunderstanding and even myth. pH reflects the mineral and dissolved-gas chemistry of water and how that is expressed by the concentration of hydrogen ions or hydroxide ions in water. While pH has a scale of 0–14, a pH range of 6–9 is considered normal for natural (unpolluted) waters; as such, it represents the lower and upper limits for the environmental quality standard (EQS) and one of the numeric limits – others being suspended solids and visible oil and grease – prescribed on most discharge permits issued by the Environment Agency.[1,2] Monitoring of pH is required for most permitted discharges, necessitating collection of water samples for analysis in a laboratory accredited by the UK Accreditation Service.

Pollution can alter the pH of water to make it either more acidic (<pH6) or more alkaline (>pH9). Alkaline leachates that commonly affect drainage water on construction and electrical infrastructure sites have the potential to cause EQS exceedances in watercourses and other receiving waters, leading to the deterioration of aquatic life. It is an offence to fail to comply with environmental permit limits or to contravene their conditions under the Environmental Permitting (England and Wales) Regulations 2016.[3]

THE NATURE OF THE pH SCALE

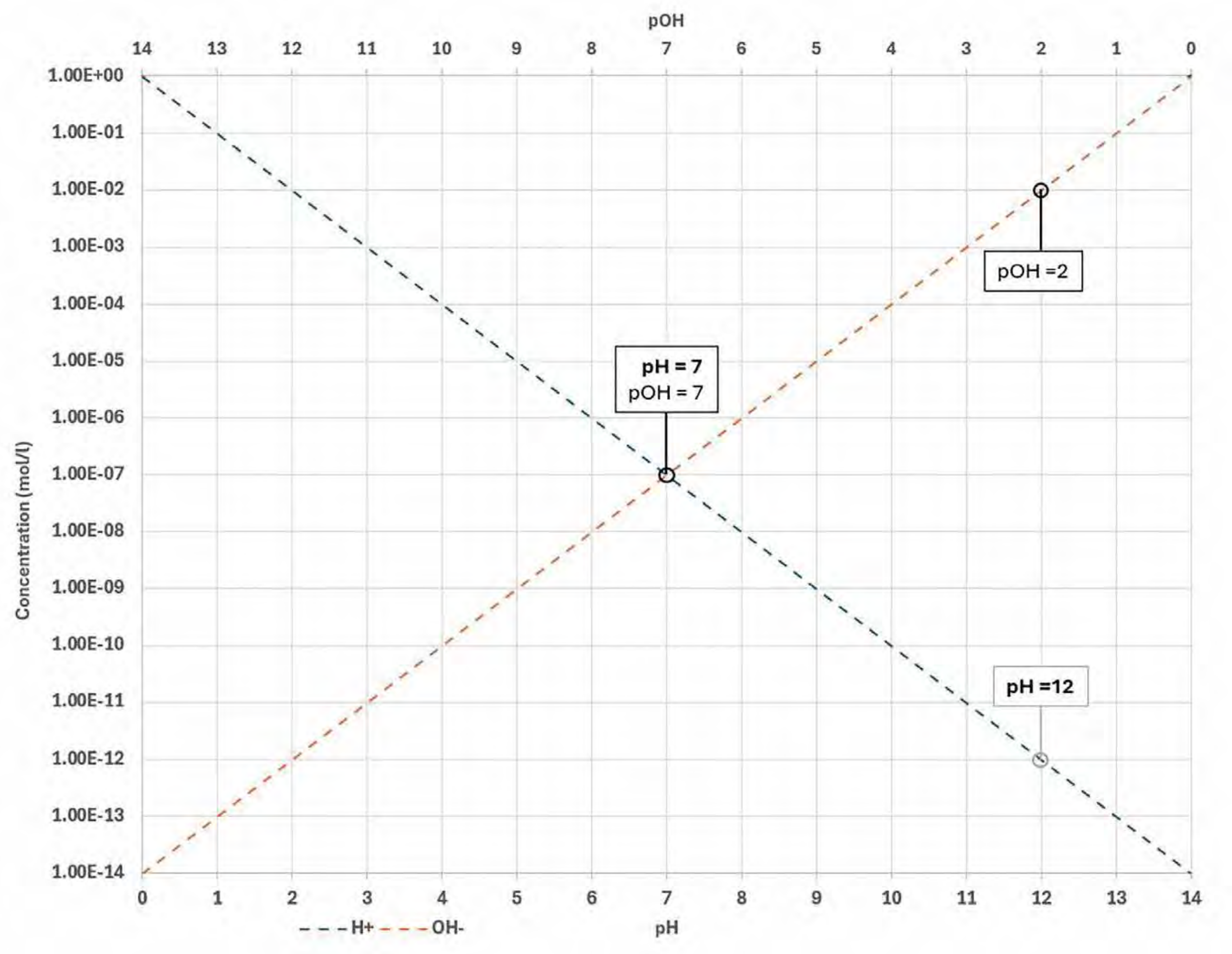
Every 10 million molecules of neutral (neither acidic nor alkaline) water contain one hydrogen ion and one hydroxide ion held in solution at equilibrium. An acidic pH is due to excess hydrogen ions tipping this equilibrium relative to hydroxide ions, whereas an alkaline pH is due to excess hydroxide ions tipping the equilibrium.

pH is a direct measure of acidity – defined as the negative log of the hydrogen ion concentration measured in moles per litre (mol/l) – the unit of measurement representing 6×10^{23} atoms or molecules in one litre. Pure water, without any dissolved carbon dioxide (CO_2) from the air, has a neutral pH of 7, located midway along the pH scale, describing equal concentrations of hydrogen and hydroxide ions of just 1×10^{-7}mol/l each (see **Figure 1**).

While pH represents the acidity of water, pOH – the negative log of hydroxide concentration – represents the hydroxide alkalinity. The total of pH and pOH is always 14, whatever the combination (see **Figure 1**). For example, an alkaline water of pH12 is also a pOH value of 2, having a hydroxide concentration of 1×10^{-2}mol/l – or one hydroxide ion for every hundred molecules of water. Although pH is specifically a measure of acidity, it is also indirectly a measure of hydroxide alkalinity since a high pH represents low concentrations of hydrogen ions and high concentrations of hydroxide ions.

Unlike chemical concentration data reported by a laboratory (e.g. chloride or dissolved iron), the pH scale is logarithmic: each successive whole-number increase in pH value represents an order of magnitude increase in hydroxide alkalinity in mol/l (see **Table 1**). For this reason, pH in the realm of construction site drainage should be thought of as the hydroxide alkalinity behind the logarithm.

Myth: Fine-grained limestone aggregate can raise the pH of a site's drainage to pH12.5. At one site, this myth was perpetuated as an explanation for the high pH of the drainage. However, natural interactions with calcium carbonate ($CaCO_3$) minerals in limestone (e.g. calcite) typically only raise the pH of fresh rainfall (equilibrated with atmospheric CO_2 at pH5.6) to pH7.3–8.2 (demonstrated using the PHREEQC model[4]). Baseline groundwater and surface water can reach the upper end of pH8, but rarely more than pH9. Therefore, natural materials in Britain's soils, subsoils and aquifers bring about only relatively modest increases in the pH of rainwater (equivalent to an increase in hydroxide alkalinity of 0.17mg/l for a maximum pH9).



▲ **Figure 1. Hydrogen and hydroxide ion concentrations at different pH/pOH values in pure water.**

TABLE 1: SUMMARY OF pH, pOH AND HYDROXIDE CONCENTRATIONS (>pH7)				
pH	HYDROXIDE ION CONCENTRATION			HYDROXIDE ALKALINITY AT pH12 (%)
	pOH	mol/l	mg/l	
14	0	1	17,000	-
13	1	0.1	1,700	-
12	2	0.01	170	100
11	3	0.001	17	10
10	4	0.0001	1.7	1
9	5	0.00001	0.17	0.1
8	6	0.000001	0.017	0.01
7	7	0.0000001	0.0017	0.001

Notes on how hydroxide concentration was calculated from pH:
pH = $-\log([H^+])$ where $[H^+]$ refers to the molar (mol/l) hydrogen ion concentration.
pOH = 14 – pH (e.g. pH12 becomes pOH2, see Figure 1).

pOH can then be used to back calculate hydroxide concentration in mol/l:
$[OH^-] = 1 \times 10^{-pOH}$.

Shading represents neutral pH7 and pH12 (typical of alkaline issues on construction sites) with percentages showing the scale of increases.

▲ **Figure 2. Photographs of typical field pH measurements from site drainage that has been affected by alkaline materials. (© SLR Consulting Ltd)**

In the construction and electrical infrastructure sectors, however, anthropogenically influenced alkaline issues are commonly detected during monitoring of site drainage due to increased concentrations of hydroxide ions released by calcined products (e.g. quicklime [CaO], cement), resulting in pH values exceeding pH10 and even reaching pH12 or pH12.5 (equivalent to the pH of household bleach) prior to treatment (see **Figure 2**). Therefore, the rise from pH8 (typical of baseline surface water) to pH12 (typical of site drainage affected by calcium hydroxide), involves an increase in hydroxide concentration of five orders of magnitude – from 0.0017 milligrams per litre (mg/l) to 170 mg/l (see **Table 1**).

ALKALINE CONSTRUCTION MATERIALS

The construction and electrical infrastructure sectors use a variety of materials that either contain, produce or release calcium hydroxide ($Ca(OH)_2$), a substance that, if allowed to reach equilibrium with pure water, can result in values close to pH13; in the absence of buffering by dissolved CO_2 and mixing with other inputs of water, this can result in maximal observed values of pH12.5 in water samples on site. Concrete wash-out leachate, cement-bound sand, ground granulated blast-furnace slag and quicklime represent potentially potent sources of calcium hydroxide in water entering site drainage from construction activities prior to discharge into the off-site water environment.

Myth: Construction effects are short-lived. The historical scarcity of water quality monitoring and the rarity of reporting perpetuate the myth that pH effects from construction are temporary and that longer-term effects are rare. Lime stabilisation of clay-rich soils prior to development of a site is undertaken to produce a soil that can be worked more easily with machinery during construction. Dissolution of any excess quicklime and the formation of cementitious bonds release hydroxide ions that can raise the pH of any soil water trapped within the stabilised platform. Any earthworks made through a low-permeability lime-stabilised platform (e.g. for underdrainage, utilities or high-voltage cables) or inadequate compaction of the platform can provide a pathway for water to interact with any excess lime or calcium hydroxide and transfer alkaline leachate to off-site water receptors.

Cement-bound sand is a 1:14 mixture of cement and sand, which is used throughout the construction industry for the installation of electrical infrastructure for underground cabling.

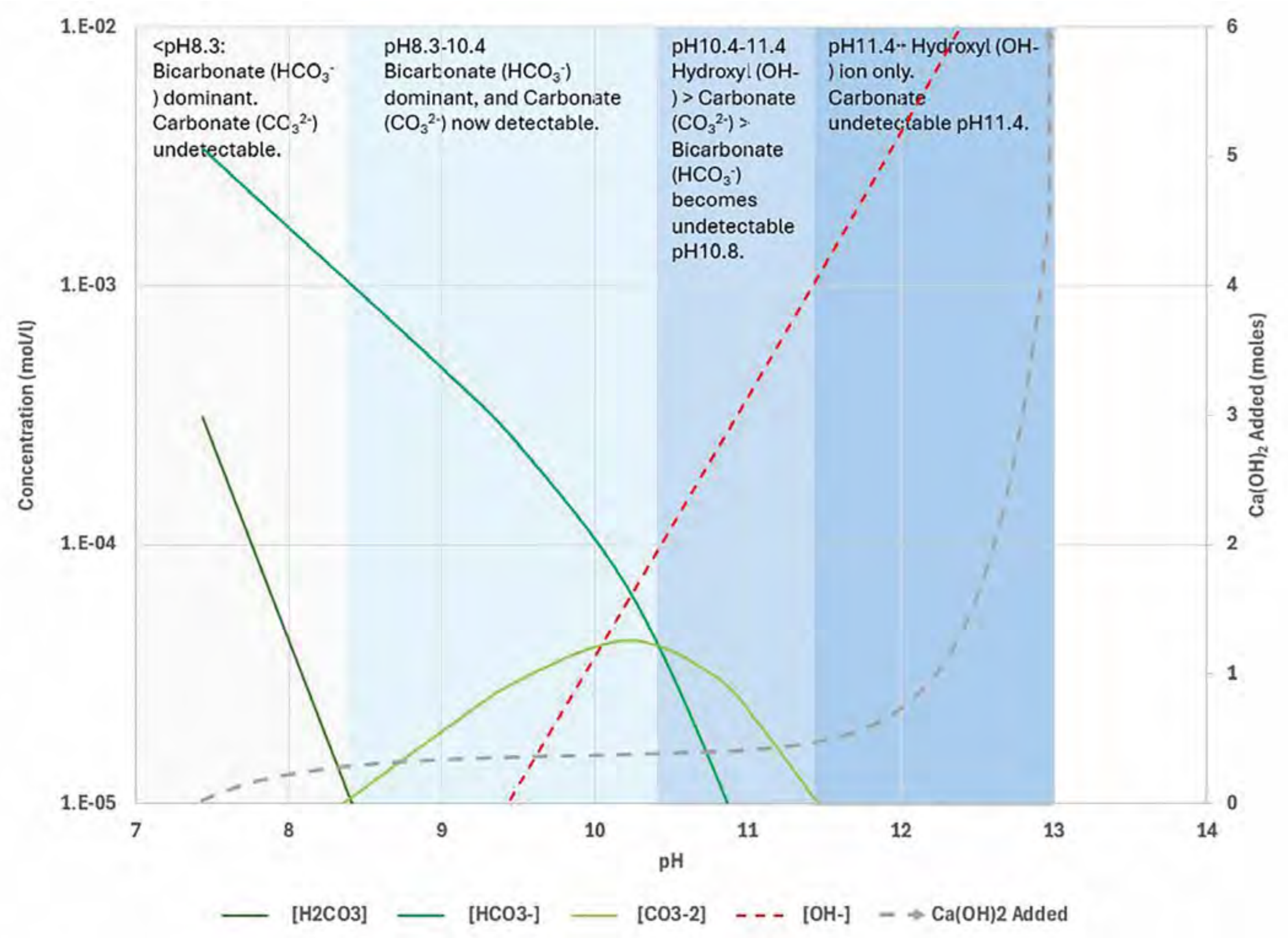
Despite the relatively low proportion of cement in cement-bound sand, the creation of bonds between sand grains during the concrete-curing process, releases hydroxide ions into groundwater in the trenches, which gather and transmit high pH water into run-off, attenuation ponds and watercourses. Cement-bound sand is commonly responsible for pH effects and the need for treatment, extending months to years into the operational phase at electrical infrastructure sites. For concrete, the main alkaline pH risk is from wash-out water that is disposed of incorrectly, without best practice wash-out facilities.

HOW ALKALINE WATERS MANIFEST ON SITE

From a monitoring perspective, it is useful to understand how quickly pH and the concentrations of other parameters in the water change in response to the addition of calcium hydroxide. Changes in the bicarbonate and carbonate chemistry in samples can provide assurance of the accuracy of pH measurements and that strongly alkaline pH measurements are not erroneous.

As calcium hydroxide is added progressively from alkaline materials, the pH in water increases rapidly (see **Figure 3**). Above pH10, the hydroxide ion concentration reaches 'major ion' type concentrations, exceeding concentrations of natural bicarbonate and carbonate alkalinity.

As the pH exceeds pH10.4, the bicarbonate concentration is surpassed by that of carbonate. Between pH10.4 and pH12.5, the carbonate is reduced by a gradual, passive neutralisation reaction between calcium hydroxide and atmospheric CO_2 resulting in the precipitation of calcium carbonate ($CaCO_3$) (the limewater test for CO_2 in school chemistry). This is observed as



▲ **Figure 3. Simulation of pH, hydroxide ion and carbonate equilibria with additions of calcium hydroxide to water. (Source: Created using the PHREEQC model[4])** a cream-coloured precipitate in site drainage that contributes to the presence of silt and the need for treatment of suspended solids. At high pH and with limited CO_2 present, carbonate ions are totally consumed. Therefore, a sample containing either more carbonate than bicarbonate or neither provides important quality assurance of a high pH measurement.

TREATMENT AND COMPLIANCE

pH issues are so common and expected in the construction and electrical infrastructure sectors that, under an environmental permit, treatment is normally required to achieve compliance with the pH9 limit prior to discharging to a watercourse.

Myth: Dilution solves the problem. The pH of water is too often considered in the same way as for a chemical parameter concentration, leading to the idea that by diluting effluent it is possible to achieve compliance. But to confidently comply with the pH9 threshold, each litre of water at pH12 would have to be mixed with 10,000 litres of water at pH7 (see **Table 2**), which is neither realistic nor practical.

The best practice approach accepted by the Environment Agency is to treat alkaline water with CO_2 gas in a lamellar clarifier unit like a Siltbuster™ (or equivalent unit) to neutralise the alkalinity, actively producing a calcium carbonate sludge for disposal at a licensed waste facility.

CONCLUSION

While pH is commonly used as a general water quality indicator that has an EQS and often permit limits, it is also an important indicator of drainage issues resulting from alkaline construction materials. Failing to plan or budget for medium- to long-term pH correction treatment is all too common for construction projects.

The pH risk of cement-bound sand to water quality is starting to be recognised and included in environmental impact assessments, raising awareness within infrastructure firms of the risks and need for design mitigation at an early stage during project design. Although guidance on potential pH impacts is currently scarce, the construction industry is starting to recognise the potential for pH issues in site drainage, the importance of its careful monitoring, and the emerging potential for alternative products that do not result in pH effects (e.g. bentonite polymer, which is now used on some sites). Experience has shown that there is the potential for a widespread water quality problem that may not be noticed. To avoid being caught out, site managers need to monitor the water quality of any discharges regularly and have a plan ready at the earliest stage for active pH treatment should pH9 be exceeded. ES

Dr Craig Speed is a Technical Director at SLR with over 20 years of postdoctoral experience in water quality monitoring, discharge permitting and associated water quality modelling, and the Water Framework Directive. His work experience has included water quality specialist roles on significant linear infrastructure projects for both major electrical infrastructure and national railway projects. Part of this work has been in the provision of water quality advice on sites experiencing alkaline pH issues and acquisition of environmental permits for discharges being treated for pH issues.
craig.speed@slrconsulting.com

TABLE 2. MIXING RATIOS NEEDED TO ACHIEVE pH COMPLIANCE BY DILUTION ALONE (WITHOUT APPROPRIATE AND BEST PRACTICE TREATMENT)

MIXING (OR DILUTION) SCENARIOS		HYDROXIDE ALKALINITY AND pH FOLLOWING MIXING	
OF WATER AT pH12 (LITRES)	WITH WATER AT pH7 (LITRES)	HYDROXIDE ION CONCENTRATION (mol/l)	pH
1	0	1.00E-02	12.0
1	1	5.00E-03	11.7
1	10	9.09E-04	11.0
1	100	9.91E-05	10.0
1	1,000	1.01E-05	9.0
1	10,000	1.10E-06	8.0
1	100,000	2.00E-07	7.3

REFERENCES

1. HM Government (2015) The Water Framework Directive (Standards and Classification) Directions (England and Wales). https://www.legislation.gov.uk/uksi/2015/1623/pdfs/uksiod_20151623_en_auto.pdf (Accessed: 20 May 2025).
2. Environment Agency and Department for Environment, Food & Rural Affairs (2016) *Surface water pollution risk assessment for your environmental permit.* Guidance. https://www.gov.uk/guidance/surface-water-pollution-risk-assessment-for-your-environmental-permit (Accessed: 20 May 2025).
3. UK Statutory Instrument (2016) Environmental Permitting (England and Wales) Regulations 2016. https://www.legislation.gov.uk/uksi/2016/1154/contents (Accessed: 20 May 2025).
4. US Geological Survey (2025) *PHREEQC Version 3.* https://www.usgs.gov/software/phreeqc-version-3 (Accessed: 20 May 2025).

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Tel +44 (0)20 3862 7484
Email info@the-ies.org
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