



# Chapter 13: Science and Sustainable Development

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## SUMMARY

The so-called ‘scientific method’ is just one of many approaches to understanding the world around us, but it has special significance in the world today. For two centuries or more the scientific method has proven its worth as an especially effective way of learning about the world and developing solutions to problems. Policy-makers concerned with the project of sus-

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tainable development often like to be seen to be ‘listening to the science’, and scientific data can command a particular kind of authority based on a shared perception of the objectivity and logical rigour associated with the scientific method. At the same time, science can be less objective than it seems at first sight: research is often deliberately steered (by funders and other stakeholders) in particular directions for particular purposes, and all science takes place within a political and cultural context. Scientific knowledge also influences sustainable development by its effect on public discourses, for example by contributing to public understanding of environmental crises, their causes, and possible solutions; and yet, relevant scientific knowledge sometimes has little effect on discourses, as it is often intentionally or unintentionally ignored. Thus, the relationship between science and sustainable development is more complex than it might at first appear.

In the first part of this chapter, we explore the scientific method and its special claims with regard to knowledge production. Science can play at least three distinct roles in relation to decision- and policy-making for sustainable development: it can deliver new concepts about the world around us, which shape public and political discourse; it can assist the development and implementation of new policy instruments, e.g. new technologies or management tools, based on scientific understandings of cause and effect; and it can offer symbolic legitimacy for decisions that might already have been made on other criteria. We then look at how science interacts with sustainable development in practical terms. We present several different (co-existing) models for the way that science feeds into decision- and policy-making. We ask whether scientists or policy-makers (or both!) need to be better educated about each other’s cultures, practices, and priorities, and discuss how so-called ‘boundary organisations’ can help to communicate between the two camps. (These topics are taken up in more detail in ‘Chapter 14: Science-Policy Interfaces and Sustainable Development: Institutionally Bridging the Knowledge–Action Gap’, this volume by Velander and colleagues.)

In the second part of the chapter, we look at three case studies of the interaction between science and sustainable development. These case studies include (i) the effect of chemical pesticides on ecosystem integrity and human health; (ii) degradation of forest ecosystems; and (iii) exploitation of Arctic oil and gas resources.

## LEARNING GOALS

By engaging with this chapter, the reader will:

- develop a critical understanding of the meaning/uses of the term ‘science’ (in relation to systematic knowledge production, more broadly understood);
- cultivate an understanding of different ways in which science can be relevant to sustainable development policy;
- understand the various ways in which science and SD policy may interact;
- gain insights into ways in which the relationship between science and sustainable development could become more effective in the future.

## INTRODUCTION

A brief survey of the environmentalist literature will quickly show that many people believe that science and technology will be critical to a brighter future for humanity. For example, Microsoft co-founder Bill Gates (2021) has written passionately about the need to expand scientific research to develop technologies such as a cure for malaria, better nuclear reactors, and geoengineering techniques that will cool the planet; and indeed, he has sunk a lot of his own money into trying to speed up the rate of scientific research. Critics of such unrestrained *technophilia* (e.g. Vettese & Pendergrass, 2024) are not slow to point out that many of the world’s problems, not least global warming, have come about as the unintended consequences of past scientific innovations. Nonetheless, science underpins mainstream sustainable development policy-making in many ways. The scientific assessments of the Intergovernmental Panel on Climate Change (IPCC) have become the bedrock upon which many sustainable development (SD) programmes are founded, while SD-facing organisations such as the United Nations Environment Programme (UNEP) or Food and Agriculture Organization (UN-FAO) routinely use and sponsor scientific research as part of their policy development processes. Scientific research is even called upon to support arguments *against* technology, or for low-technology development, or for development that privileges socio-political change over technological change: for example, against unrestrained use of artificial pesticides, or in support of agroforestry, or in

favour of granting land tenure to Indigenous communities, wherever the scientific method can provide evidence of positive outcomes. Among more radical groupings, the Degrowth movement, which argues (to varying degrees) against endless economic growth, presents itself as a ‘scientific research paradigm’ (Schmelzer et al., 2022). On the surface at least, nearly everyone seems to agree that scientific research is a critical part of the overall project of SD, since the knowledge that science generates is necessary to underpin and justify the policies on which sustainable development depends.

Our aim here is to understand the relationship between science and SD, taking a critical perspective that is informed by our position as researchers with backgrounds in the natural sciences (ecology and geology). Our collective experience is consistent with the academic literature on this topic, in that we have found the relationship between science and SD to be far from simple. Scientific knowledge can be used to underpin policy and decision-making, not least by contributing to public and political discourses. But the relationship between science and policy works both ways: scientific research projects are themselves shaped by demands from policy-makers and other stakeholders; and not only that, science takes place in the context of the public discourse, and scientists are influenced by that discourse when choosing what to study and how to study it. Where science is relevant to SD, some mediation or translation is usually needed to make research results meaningful to non-scientific audiences. Much relevant research is ignored or overlooked, but occasionally individual studies can have an enormous influence on politics and society. And some scientific research topics, for instance on geoengineering, are deeply controversial in SD circles (e.g. McDonald, 2023). So, how exactly should science influence our thinking in SD? And how far should the needs of SD (and policy-makers) influence science? These are questions that will be introduced in this chapter, through a survey of the academic literature and discussion of three case studies. Chapter 14 takes a more detailed look at the so-called science-policy interface and considers how that interface could function more effectively.

## ‘SCIENCE’, KNOWLEDGE PRODUCTION, AND SUSTAINABLE DEVELOPMENT

### *What Is Science?*

We are so used to hearing about ‘science’ and ‘scientists’ in everyday life, often associated with imagery of test tubes, white lab coats, mathematical equations, and expensive-looking gadgets, that it might come as a surprise to find that scientists themselves are often unsure about how to describe or define what they do. Many non-scientists, including politicians and policy-makers, appear to think of ‘science’ as a reliable source of facts about the reality of the world around us. Our stereotypes of science have a long history, reflecting perhaps the way that science was perceived to be performed in the so-called hard sciences of physics and chemistry at a time when (in the West at least) the scientific method was only just beginning to challenge older forms of knowledge production (which often were based on the perceived authority of religious texts or classical authors such as Aristotle or Plato). However, Oxford Languages,<sup>1</sup> publishers of the Oxford English Dictionary, offer this remarkably inclusive definition of science: ‘the systematic study of the structure and behaviour of the physical and natural world through observation, experimentation, and the testing of theories against the evidence obtained’. This definition aligns well with the commonplace idea of ‘science’ as being evidence-based and systematic, but there is no sense here that ‘science’ has to be tied to a laboratory. The inclusiveness of the Oxford definition reflects the fact that many parts of what might previously have been considered humanities disciplines (Geography, Psychology, Politics, Economics, and so on)—perhaps due to so-called physics envy, or at least borrowing the hypothetico-deductive model from physics (Nichols, 1993)—reinvented or restyled

<sup>1</sup> At least, this is the definition that Oxford Languages supplies to Google, which arguably makes this one of the most widely-accessible definitions available in English. The Oxford English Dictionary itself offers ten separate definitions which span the multiple ways in which the term ‘science’ has been used historically and at the present day, some of them much broader than this definition (e.g. ‘a particular area of knowledge or study’) and some couched in more technical language (‘A branch of study that deals with a connected body of demonstrated truths or with observed facts systematically classified and more or less comprehended by general laws, and incorporating trustworthy methods (now esp. those involving the scientific method and which incorporate falsifiable hypotheses) for the discovery of new truth in its own domain’) but essentially equivalent to the definition discussed here (Oxford English Dictionary Online, [n.d.](#)).

themselves as ‘social sciences’ or ‘behavioural sciences’ in the second half of the twentieth century. In doing so they often adopted more numerical methods, tried to identify ‘laws of nature’, and organised their knowledge around systems thinking, so that ‘science’ was no longer seen to apply just to the physical and natural world but to social, political, and economic worlds, too. In recent decades the position has changed further: there has been an increasing acceptance that quantitative, hypothesis-driven science can provide at best a limited understanding of the world. It is hard to understand (for example) people’s motivations, or values, or happiness, through numbers alone. Thus increasingly, qualitative data—such as data from surveys, focus groups, interviews, participatory methods, and so on—are seen as a valuable part of scientific research in many fields (Nelson, 2016). There has also been a reappraisal of the value of forms of knowledge that fall outside of the established Western scientific method, such that organisations such as IPBES (Velandar et al., ‘Chapter 14: Science-Policy Interfaces and Sustainable Development: Institutionally Bridging the Knowledge–Action Gap’, this volume) now include ‘indigenous’, ‘local’, or ‘traditional ecological knowledge’ (TEK for short) in their assessments.

Thus, the Oxford definition of science as “[any] systematic study... of the natural [and social, economic, political...] world through observation, experimentation, and the testing of theories against evidence” is a useful one for SD, as it admits a wide range of sources of knowledge while still insisting that systematic thinking, observation, and evidence should be at the heart of what we consider to be ‘science’. This definition rules out uninformed opinion, speculation, and theories that do not stand up to testing as being inadmissible under the banner of ‘science’ (though all three are features of the real-world policy discourse!).<sup>2</sup>

Interestingly, the Oxford definition excludes any mention of ‘facts’ or ‘reality’, two concepts that are often associated with science. Many practising scientists have a very nuanced view about the extent to which science can discover ‘facts’. For example, Alan Chalmers, in his classic book *What Is This Thing Called Science?*, points out that scientists have to be trained

<sup>2</sup> Discussions of ‘science-into-policy’ are, of course, shaped by anglophone thinking based mainly on English vocabulary, and arguably, so is the whole field of practice. It is interesting to speculate whether the interface between research and policy would be different if English had adopted a word more like the German ‘Wissenschaft’ (meaning something like ‘knowledge production’) at an early stage to describe the full range of scholarship that happens in universities, research institutes, and elsewhere.

to make observations (Chalmers, 2013). A lay person looking at a soil profile will see very little compared to a trained and experienced soil scientist, who is used to describing soils in terms of their stratigraphy, colour, texture, and mineralogy. Furthermore, an experienced soil scientist will have a strong conceptual framework that guides their understanding of what those properties might mean in terms of the history of the soil, or its biology, or its fertility, and they will be looking for particular features depending on the reason for their study. Thus, two observers who have been trained differently, or who have different research questions in mind, or even who have different cultural backgrounds, are likely to make different observations about any given phenomenon; in other words, the ‘facts’ they produce always include some degree of interpretation and are shaped by the questions being asked, which in turn are shaped by the social and cultural context.

Philosophers of science have gone on to point out many other ways in which the ability of science to reveal ‘the truth’ is limited, not least the point that it is rarely if ever possible to prove conclusively that a theory is correct (it is much easier to demonstrate that a theory is wrong, i.e. that it is not compatible with observations). In principle, any theory is merely provisional, waiting to be overturned (‘falsified’, in the language of Popper, 1934). Indeed, there have been some well-discussed instances where a scientific consensus or ‘paradigm’—a whole body of well-developed theory—has been shown to be entirely wrong (Kuhn, 1962). A classic example is the realisation by geologists in the 1960s that the Earth’s continents ‘drift’, slowly changing position over geological time. In this case a handful of very convincing new observations led, within the space of a few years, to a radical overhaul of the whole discipline, throwing out tracts of theory about subsidence and emergence of areas of the Earth’s crust, and literally requiring the textbooks to be rewritten (e.g. van Andel, 1992). Some people have extrapolated from examples like this one to suggest that the whole of science rests on equally shaky foundations, and that any existing branch of theory is quite likely to turn out to be wrong, which would be a serious challenge to the authority of science if it were true. However, it seems likely that much, if not most scientific advance comes about through gradual refinement, development, and improvement of existing theories, rather than their out-and-out replacement (e.g. Sanbonmatsu & Sanbonmatsu, 2017; Layman & Rypel, 2023),<sup>3</sup> a process

<sup>3</sup>There is even a case to be made that the rate of radical innovation actually drops as the number of publications in a scientific field builds up: it becomes harder and harder to chal-

which Kuhn (1962) referred to as ‘normal science’. Nonetheless, practising scientists working at the forefront of their disciplines are, in our experience, usually very aware that theories exist to be tested, that sometimes theories fail those tests, and that all observational data need to be interpreted critically. But the bottom line is that ‘systematic study [based on] observation, experimentation, and the testing of theories against evidence’ now has a long track record of success in explaining features of the world around us, revealing the patterns of cause and effect, and giving us the means to intervene and change things.

### *How Is Science Relevant to Policy-makers?*

So, with some caveats, scientific research provides a source of new and (generally) reliable information about the world, much of which should be useful as we strive towards a more sustainable future. What kinds of scientific knowledge might be useful to policy-makers, and what can they do with that knowledge? Hoppe et al. (2013) suggest that science can be relevant to policy in three main ways:

- **Conceptual relevance:** in which science delivers new ideas that drive new areas of policy. A recent example would be the rising concern about the environmental effects of microplastic pollution, something that simply was not considered by policy-makers until it was raised by scientists a couple of decades ago. Another good example would be the detection of the ‘hole’ in the ozone layer over Antarctica in the early 1980s, a chance discovery that emerged from routine data collection. It very quickly raised alarm bells and resulted in rapid action culminating in the 1985 Montreal Protocol, which regulated the production and use of chlorofluorocarbons and other ozone-depleting substances. This is often cited as one of the first and most effective intergovernmental actions on a global-scale environmental problem (e.g. DeSombre, 2000).
- **Instrumental relevance:** in which science delivers an understanding of causality; that is, if one thing changes, how will another react? An example might be a hydrological model that links rainfall to flooding. Knowing how water will flow through a landscape during and

lence the overwhelming body of literature in support of the prevailing paradigm. See Chu and Evans (2021).

after a heavy rainfall event can help agencies to plan flood defences or other adaptations to avoid deaths or damage to properties. Thus, science provides ‘instruments’, tools, or technologies that help us to manage our environment. Another example of instrumental research would be the drive to develop new agricultural varieties that are resistant to drought or disease. Many governments invest heavily in agricultural research in order to maintain or improve food security.

- **Symbolic relevance:** Science can be used to legitimise decisions that have already been taken. For example, a politician might have concluded that a particular pesticide is too important economically to be banned, despite opposition from environmentalists. They might then find it useful to cite (cherry-picked?) scientific studies to justify that decision. As discussed above, ‘science’ carries a certain authority that can be used rhetorically to justify an argument; but it is also true that different studies on a topic often come to contradictory conclusions, so it is often possible to find scientific support for a range of different policy positions. The Covid-19 pandemic offered many examples of appeals by politicians to ‘science’ as justification for lockdowns and other restrictions on personal freedoms, which otherwise might have been more strongly resisted (e.g. Kreps & Kriner, 2020).

### *How Do Science and Policy Interact?*

Having suggested that science is relevant to sustainable development policy in at least these three ways, the next question is ‘How do science and policy interact?’ It is rarely the case that a scientist independently comes up with an important piece of knowledge, talks directly to a policy-maker, and sees their idea immediately written into a new policy document. There are necessarily limits to the skills and experience of researchers, and few scientists have direct connections with politicians or policy-makers. More commonly, research informs policy via a variety of intermediary people or organisations, which we will discuss below.

In fact, the interaction between science and policy-making goes both ways: policy-making affects science, just as science affects policy-making. All research takes place within a particular social, political, and economic context. Politicians have a lot of control over (for example) which fields of study receive government funding and which do not. Research is also funded by industry, private donors, and foundations, and advocacy groups, including development and conservation organisations, all of which have

their own political objectives. Hence the needs and aims of policy-makers have a big influence on what scientific research is carried out.

Keller (2009), focusing on environmentalist perspectives, suggested that there are several ways in which science and policy may interact:

- What Keller called the ‘**rationalism**’ model, in which policy-makers decide their goals, then commission research to help them to achieve those goals. In this model, policy leads science. For example, policy-makers might decide that their goal is to reduce the damage caused by flooding, then commission research that will identify or develop tools to help them to do so.
- The ‘**logical positivism**’ model, in which scientists are left to explore the world freely. In doing so, they will inevitably identify problems for society (e.g. pesticide poisoning, the ozone hole, global warming, plastic pollution, etc.). The goal of policy-makers is, or should be, to address the problems identified by scientists: in this model, science leads policy. Recognising that policy-makers rarely, if ever, follow science quite so faithfully, Keller proposed a modified ‘**soft logical positivism**’ model in which politicians decide which of the problems presented to them to prioritise, and how to tackle them.
- A ‘**pragmatic incrementalism**’ model, in which researchers accept that there are limits to the extent to which scientific evidence can challenge the status quo. Keller points out that scientists are often very aware that some topics for research are more acceptable to funders than others, which means that science has a tendency to produce ‘more of the same’ rather than startlingly new insights. Scientists are also often reluctant to suggest really radical solutions that will completely solve the problems they identify, because they recognise that such solutions could be a ‘hard sell’ to the voting public; so, they tone down their advice, or even avoid researching some topics altogether. Examples of this emerge on a daily basis in the discourse around climate change, with some researchers insisting on an urgent need for complete and rapid phase-out of fossil fuel use, and others arguing that such thinking is hopelessly unrealistic as a policy goal and instead advocating technologies such as geoengineering, or carbon capture and storage. There are some examples of this ‘incrementalist’ approach bearing long-term fruit. For example, in the early 1960s Rachel Carson (see below) called, not for a total ban on the pesticide dichlorodiphenyltrichloroethane (better known as DDT)

but for regulation and more care in its use—a much more achievable goal at the time. Nonetheless, over the course of twenty years, public feeling on the matter changed to the point where it became politically pragmatic for scientists to make the case for a total or near-total ban on DDT, which was eventually enacted in most countries around the world.

Stone (1989) contributed a different view on the interaction between science and policy. She argued that science, policy, and the public are caught up in a battle to construct and champion competing **narratives** about the world around us, which in turn influence the balance of political opinion within society. Science can be used to lend weight to one or the other—or often both—sides of a debate; here the usefulness of science rests on its (perceived) access to unbiased ‘fact’, which provides rhetorical support to an argument. Thus, for example, the climate change debates of the early 2000s often featured the huge compilation of scientific evidence for anthropogenic climate change represented by the IPCC’s Assessment Reports, on the one side, versus contrary arguments constructed by climate change deniers whose authority was based on (we would argue) a misreading of scientific research into natural climate change (driven by cycles in the sun’s output, for example). These different storylines—with their differing implied policy responses—competed directly for public support, often head-to-head in so-called balanced programming by media outlets such as the British Broadcasting Corporation (BBC). That both sides felt it necessary to lean on science in support of their views reflects the prevailing view that any kind of rational decision-making should be based on objective evidence. An alarming aspect of at least the anglophone political world in recent years has been the development of what some consider to be a ‘post-truth’ era in public discourse, infamously summed up in the claim that ‘the people of this country [the UK] have had enough of experts’ (Michael Gove, UK Justice Secretary: Youtube, 2016). Arguably, there has been an erosion of the public’s sense that ‘experts’ can be relied upon as disinterested ‘speakers of truth to power’.

Stone (1989) made another interesting point, that many environmental narratives fall into one or the other of two types. The first type is a narrative of **control**: the sense that science and technology are empowering us to shape nature with increasing freedom. This narrative reflects the techno-optimism of Western society that was particularly strong during the 1940s to 1960s, a period when, in the wake of the Second World War and during

the height of the ‘space race’ between the USSR and the USA, science and engineering were full of promise to build a better world. Stone’s second narrative type is a narrative of **decline**, which arguably took off during the 1960s, although it has much deeper historical roots (e.g. Marsh, 1864). This is a narrative that foregrounds the hubris of humanity in trying to control nature and in which science often plays the part of the villain: no technology seems to be without its unintended harmful consequences, from the steam engine onwards. Both narratives, of control and decline, can be seen to be competing today in sustainable development, for example in the debate between the techno-optimists and geoengineers, on one side (e.g. Gates, 2021), and the rewilders (e.g. Monbiot, 2013) and half-earth conservationists (Wilson, 2016), on the other. These two narratives—one inherently more optimistic than the other—arguably are just as important in shaping the kinds of research that scientists undertake, as research is in providing new material to fuel the narratives.

This discussion of the relationship between society and science challenges the claim that scientists have special access to the ‘objective truth’. Given the expectations that society seems to hold, many scientists feel that they must at least *appear* to be detached and objective, if the ‘facts’ they produce are to be credible as such. But behind the scenes, of course many scientists choose their research topics to reflect their personal values or politics. They cannot help but be influenced by the narratives that structure their thinking, both within and beyond the institutions where their laboratories are situated. A variety of ‘coping strategies’ can be observed among researchers. Some cling to the principle of scientific detachment and try very hard to keep politics out of their work. Others accept that their work is inevitably entangled with politics and try to be frank about it. Still others would argue that scholars have a duty also to be political activists: after all, no-one is in a better position than they are to know what needs to be done to confront the problems (or opportunities) revealed by their research.

A useful ‘coping strategy’ for researchers is to keep policy at arm’s length by working with intermediaries—journalists, campaigners, or more formal ‘boundary organisations’ (also known as ‘boundary spanners’), which exist to bridge the science-policy divide. These boundary organisations range in scale, structure, and focus; examples include individual people who specialise in ‘knowledge exchange’; NGOs and advocacy groups such as the World Wildlife Fund or Greenpeace; UN-sponsored organisations such as the IPCC and IPBES; or governmental offices, such as the

Parliamentary Office for Science and Technology in the UK. These boundary organisations can help scientists to (at least claim to) maintain their objectivity, by doing the ‘dirty work’ of politics on their behalf; but equally, they provide a bridge from policy back to science, shaping research so that it is more relevant to policy-makers, by helping scientists to understand what research is needed and how it can be used. The ‘fuzzy boundary’ that results is therefore useful in practical ways both to science and to policy. Velander et al., ‘[Chapter 14: Science-Policy Interfaces and Sustainable Development: Institutionally Bridging the Knowledge–Action Gap](#)’ (this volume), will explore the role of large-scale, highly organised boundary organisations such as the IPCC and IPBES, which have become very influential in facilitating the interaction between science and policy in sustainable development at national and global scales. But first, let us conclude this chapter by looking at three case studies of science-policy interaction, to give a sense of the variety of forms that this interaction can take.

### THREE CASE STUDIES OF THE RELATIONSHIP BETWEEN SCIENCE AND POLICY

#### ***Silent Spring and the Pesticide Debate***

The publication of Rachel Carson’s 1962 book *Silent Spring* (Carson, 1962) is frequently hailed as one of the foundational events of the environmentalist movement. Sixty years on, the book still provides a master-class in the use of scientific information to develop a narrative that drives policy change. But it also forms part of a larger history in which scientific research and policy interacted over the course of several decades—and indeed still are interacting, with ongoing debates about neonicotinoid pesticides and the ‘insectageddon’.<sup>4</sup>

Rachel Carson (1907–1964) was a scientist and writer from Pennsylvania in the United States. She began her undergraduate studies as an English major but found herself drawn to study oceanography. After college she went on to work at some of the leading oceanographic institutes, then for the US Fish and Wildlife Service as a scientist, and eventually as editor-in-chief of its publications. During her time at the Fish and Wildlife Service,

<sup>4</sup>For more on Rachel Carson’s life and work, see Seager (2014), Jameson (2012), and Crist (2019).



**Fig. 1** DDT use on a landscape scale: spraying forests to control a spruce budworm outbreak (Source: Wikimedia)

she wrote a popular science book, *The Sea Around Us*, which sold so well that she left her job and took up writing full time.

One of the issues that she chose to write about was her growing concern about the indiscriminate use of organochlorine pesticides. DDT, the most well-known of this group of pesticides, was a synthetic chemical which was discovered by accident in 1942 to be a highly effective insecticide. It went on to be pressed into wartime service and saved countless lives by killing the insect hosts of diseases such as typhoid and malaria. After the war, organochlorines were quickly taken up in agriculture, forestry, and other environmental settings and were used on a large scale (Fig. 1).

Although scientists quite quickly raised concern about the possible upset to ecosystems (Wigglesworth, 1945), it took about a decade for scientific publications to begin to show that the unrestrained use of pesticides could have serious ecological consequences. Carson was well positioned to access and interpret this literature. She cited one example,

Clearwater Lake in California, which had been dosed with a pesticide in order to suppress annoying clouds of midges. The pesticides worked their way up the food chain to reach lethal levels in individuals of the western grebe, a conspicuous and well-loved bird that was characteristic of Clearwater Lake. Carson wove reams of evidence like this into her book *Silent Spring*, which opened with an alarming description of an imagined future in which ecosystems had been so disrupted that no birdsong could be heard: ‘Everywhere was a shadow of death’.

Carson’s book was serialised in a popular American magazine, *The New Yorker*, and quickly became talked about on both sides of the Atlantic. Carson appeared in person to defend her views at the US President’s Scientific Advisory Committee, which ended up siding with her against the pesticide industry. Perhaps no less influential was a TV report by CBS, viewed by upwards of 10 million Americans, ‘in which a quiet, confident Carson was opposed by a ranting spokesman for the chemical industry, while a whole parade of government witnesses proved unable to answer questions on the long-term impact of pesticides [...] the broadcast was a sensation’ (Mills, 1998).

Carson’s work is credited with laying the groundwork for a ban on DDT in the US, which came into force in 1972, eight years after her death (although, as mentioned earlier, she never advocated for a complete ban, only for less careless use). But more profoundly, she established a pattern for environmentalists to follow whereby scientific data are used to challenge the status quo. Perhaps here we have a classic example of Keller’s ‘logical positivism’ model of science-policy interaction: in this case, science led policy change by identifying an emerging problem that demanded a solution. But it is worth noting that Carson played an important role as an intermediary between science and policy. Her writing skills, in particular her talent for synthesising information from a wide range of fields in a way that was accessible to the lay person, was critical in helping the public to understand and imagine what the science implied for the future, if unconstrained pesticide use continued. And her willingness to appeal to emotion—deliberately to alarm her readers—is a strategy that has continued to be used by many in the environmentalist movement and that may be very effective in driving change (Pacala et al., 2003), even if it risks provoking despair or burnout (Bird et al., 2024). Carson’s activism allowed scientists to maintain their ‘objectivity’ and was critically important in shaping the narrative around organochlorines. Arguably, her challenge to the ‘control’ narrative (discussed above) had an important cultural effect well beyond

the realm of pesticides, in establishing the precautionary principle in environmental politics (Løkke, 2006).

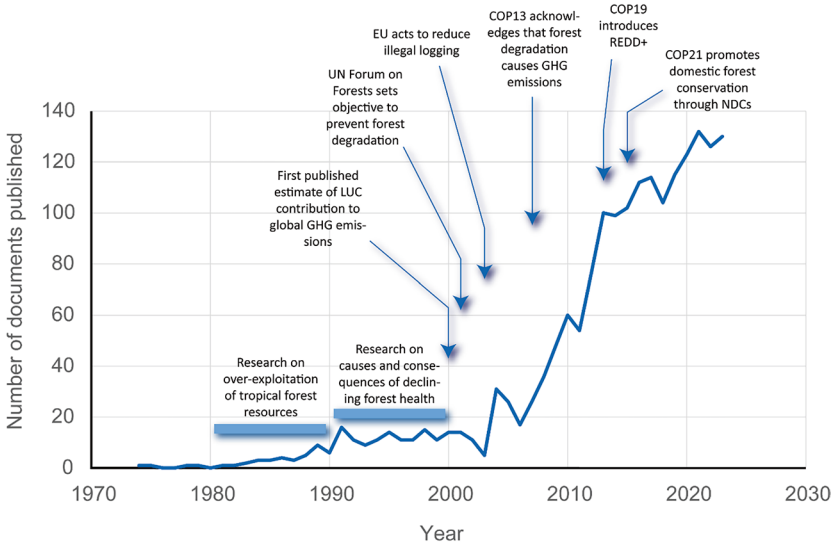
There is certainly a lot more scepticism about new technologies nowadays than there was at the start of the 1950s, to the point where ‘novel entities’—new materials and chemicals—were identified as one of the nine planetary boundaries, the limits to the ‘safe operating space for humanity’ proposed by Rockström et al. (2009). Nonetheless, it is interesting to see elements of the Silent Spring story still being repeated today. A good example is the changing policy around neonicotinoids, a new class of synthetic compounds introduced in the 1990s as cheap and highly effective pesticides—and, it was felt at the time, much safer than previous pesticides. However, they were soon suspected to pose a danger to bees and other pollinating insects, and scientists became concerned that the growing use of neonicotinoids would threaten plant reproduction and food webs (Sánchez-Bayo, 2014; Sharma & Sanyal, 2024). As just one vignette of the way that science has fed into the debate, the UK Department for Environment, Food and Rural Affairs (DEFRA) published an analysis of the scientific literature (DEFRA, 2013) which strongly criticised three peer-reviewed studies indicating that neonicotinoids are harmful and supported five alternative studies indicating the opposite, concluding that “...the risk to bee populations from neonicotinoids, as they are currently used, is low.” In response, Dave Goulson, one of the leading entomologists in the UK, argued that the five pro-neonicotinoid studies were all either irrelevant or of poor quality or had not been subjected to peer review and were therefore unreliable (Goulson, n.d.). Goulson also produced his own (peer-reviewed) analysis which concluded that “...current use of neonicotinoids is likely to be impacting on a broad range of non-target taxa including pollinators and soil and aquatic invertebrates and hence threatens a range of ecosystem services” (Goulson, 2013). The problem is that every scientific study has its weaknesses, so there is usually room for argument, although eventually the weight of evidence on one side or the other usually becomes overwhelming. In fact, as with DDT, the growing body of scientific evidence against neonicotinoids was reinforced by determined mobilisation of public opinion by vocal and eloquent scientists like Goulson (who, like Carson, has written bestselling books pitched at the general public: e.g. Goulson, 2021), environmental advocacy groups (e.g. RSPB, 2022), and consistent coverage in parts of the mainstream media (e.g. BBC, 2014). As the scientific evidence against neonicotinoids—and the weight of public opinion—steadily mounted, the

UK government (like many governments around the world) eventually concluded in favour of a complete ban on what they themselves called ‘bee-killing pesticides’ (UK Government, 2024).

### *Forest Degradation*

Tropical forests, often characterised by luxuriant and highly biodiverse ecosystems, collectively provide a wide range of ecosystem services to humanity. These services include provision of natural resources, conservation of biodiversity, carbon storage, climate regulation, and direct contributions to human well-being (Brandon, 2014). The increasing demand for timber and non-timber forest products such as edible fruit, medicinal plants, fuelwood, and bushmeat, has led to the degradation of many tropical forests and the depletion of these ecosystem services (Kissinger et al., 2012; Hosonuma et al., 2012). But there are ways to limit or prevent forest degradation, which can simultaneously promote long-term sustainable development, particularly for local and Indigenous communities. Scientists have recently begun to develop the evidence base and evaluate promising methods and strategies for forest conservation, offering these as options for policy-makers to draw on. This is a nice example of Hoppe et al.’s (2013) ‘conceptual relevance’ of science that we introduced above: science offering new ideas for sustainable development.

Perhaps surprisingly, one of the key barriers to policy development has been a lack of agreement on a unified, formal scientific definition of the term ‘forest degradation’. At its most general, forest degradation is usually understood to imply some form or other of anthropogenic intervention that leads to a decrease in the ‘quality’ of the original forest. But forest degradation can be temporary or permanent, and it can involve the loss or decline of biomass, canopy cover, species diversity, forest structure, composition, function, and/or the capacity to provide goods and services (Lund, 2009). ‘Forest degradation’ has thus become a catch-all term that can mean different things in different places, as becomes clear when we look at how different researchers have used the term in relation to their particular case study or research site. At least 84 different definitions have been used in the scientific literature (Simula, 2009)! While nit-picking about definitions is part and parcel of academic research, policy-makers need clear, simple, uncontroversial, and widely applicable definitions around which to build workable policies. It is impossible to regulate against and monitor forest degradation if no-one can agree what ‘forest



**Fig. 2** Records of Scopus documents (mainly journal articles) obtained by searching for ‘degradation’ AND ‘tropical forest’, in relation to selected events from Table 1. LUC: Land-use change; GHG: greenhouse gas; REDD+: Reducing Emissions from Deforestation and forest Degradation; NDCs: Nationally Determined Contributions (to climate change mitigation)

degradation’ actually looks like. Defining forest degradation in a way that can be measured objectively has therefore become a priority in the scientific literature over the last three decades, primarily in response to this policy need for unity on definitions.

The history of the interplay between scientific research and policy development on forest degradation is instructive. Scientific publications relating to the degradation of tropical forests were scarce before 1990 (Fig. 2). Published research between 1991 and 2003 predominantly centred on the causes and consequences of what became understood to be a widespread decline in forest health. This early scientific knowledge contributed to new environmental and climate change debates, marked by the United Nations Conference on Environment and Development held in Rio de Janeiro, Brazil, in June 1992 (Velastegui-Montoya et al., 2022), which allowed the UN member states ‘to renew the commitment to sustainable development and to ensuring the promotion of an economically,

socially and environmentally sustainable future for our planet and for present and future generations' (UN, 2012). During the last 20 years, there has been an exponential increase in scientific activity around forest degradation, with topics expanding to encompass the implications of forest degradation for carbon emissions and biodiversity loss. Natural scientists, increasingly trained to think of the Earth as a single connected system, have arguably been effective in pointing out the links between different areas of policy (e.g. climate change, biodiversity loss, ecosystem services, and poverty alleviation), revealing new synergies between different policy fields that policy-makers can exploit. However, research that genuinely considers the natural and cultural spheres together, i.e. using techniques from the natural and social sciences to address related questions, has historically been and remains much scarcer, although such interdisciplinary work is becoming more frequent as the need to integrate people, for example their livelihoods, well-being, and local knowledge, into the picture is increasingly appreciated (e.g. Honorio Coronado et al., 2025).

From at least the 1980s the scientific community was working to raise awareness of the depletion of tropical forest resources and ecosystem services (e.g. Salati & Vose, 1984; Myers, 1983; Houghton, 1991; Schmidt, 1992; Young, 1994), but it was a long time until significant international initiatives to reduce forest degradation were put in place (Table 1 and Fig. 2). Among the earliest such initiatives was the 2001 United Nations Forum on Forests, which incorporated an objective on preventing forest degradation. In 2003, the European Union introduced the Forest Law Enforcement, Governance and Trade (FLEGT) Action plan, an initiative aimed at reducing illegal logging. Notably, the Convention on Biological Diversity (CBD) incorporated assessment of ecosystem fragmentation and connectivity as indicators of forest degradation in 2005 (Simula, 2009). There were also early attempts to quantify degradation (Becker et al., 1995; Lambin, 1999) and its associated greenhouse gas emissions in tropical forests (Fearnside, 2000; Fearnside & Laurance, 2004). But it was not until 2007, during a meeting of the United Nations Framework Convention on Climate Change (UNFCCC), that the role of forest degradation in driving greenhouse gas emissions was acknowledged (COP13 Bali Action Plan). Subsequently, in 2013, conditions across nations were formulated to allow accounting for reduction of emissions resulting from avoiding degradation (in addition to deforestation) in developing countries (COP19 Warsaw Framework; Table 1).

**Table 1** Timeline of activities leading to policies to reduce forest degradation

<i>Year</i>	<i>Activity</i>	<i>Outcomes</i>
1980s	Research studies (Salati & Vose, 1984; Myers, 1983)	Awareness of the depletion and overexploitation of tropical rainforest resources.
1990s	Research studies (Houghton, 1991; Schmidt, 1992; Young, 1994)	The causes and consequences of the decline in forest health.
2000	Research study (Fearnside, 2000)	First estimation of the contribution of land-use change, including deforestation and forest degradation, to global greenhouse gas emissions.
2001	UN Forum on Forests	Inclusion of an objective on preventing forest degradation.
2003	EU policy	EU Forest Law Enforcement, Governance and Trade (FLEGT) action plan to reduce illegal logging.
2005	International report	Convention of Biological Diversity (CBD) technical series No. 30 includes a chapter on ecosystem fragmentation and connectivity responsible for forest degradation.
2007	UNFCCC Conference of the Parties (COP13)	Bali Action Plan acknowledges that forest degradation produces greenhouse gas (GHG) emissions.
2013	UNFCCC Conference of the Parties (COP19)	Warsaw Framework defines conditions for Reducing Emissions from Deforestation and forest Degradation plus additional forest-related activities (REDD+) in developing countries.
2015	UNFCCC Conference of the Parties (COP21)	Paris Agreement promotes domestic mitigation measures through Nationally Determined Contributions (NDC).

One lesson to take from this history is that the path from science to real change in the world may involve a prolonged effort, sustained over decades, by many individuals and institutions. Alongside these efforts to develop policies to reduce forest degradation, there has been a sustained research focus on developing innovative methodologies for monitoring and quantifying carbon emissions from forest degradation. Changes in canopy cover and biomass caused by forest degradation can be subtle and therefore challenging to monitor using remote sensing (satellite imagery; see Bolch, 'Chapter 12: Remote Sensing for Sustainable Development', this volume; Lambin, 1999). However, researchers have developed various methods that allow direct mapping of canopy and forest structural

changes, and indirect mapping of degradation through sophisticated modelling approaches that incorporate proxy variables such as distance to infrastructure and populated centres (Herold et al., 2011). Other approaches rely on field data sets collected through national forest inventories, permanent forest monitoring plots, commercial forestry data sets, and proxy data from domestic markets (Herold et al., 2011). As well as its value in demonstrating the scale of the problem (‘conceptual’ relevance)—depending on definitions, as much of 50% or 10 million km<sup>2</sup> of tropical forest can be considered ‘degraded’—this kind of technology-driven science is an example of Hoppe et al.’s (2013) ‘instrumental’ relevance of science to policy-making (and, in this case, enforcement). Similar instrumental research has focused on developing techniques for forest restoration, sustainable management, and conservation as a general basis for achieving the UN’s Sustainable Development Goals in the tropics (e.g. life on land, climate action, good health and well-being).

### *Arctic Oil and Gas*

Our third case study looks at the relationship between science and sustainable development from a very different angle: what happens when there are very few scientific data to work with, and where the scientific knowledge in question underpins activities which seem to conflict with some of the central goals of sustainable development?

The Arctic is a particularly important region to consider in terms of twenty-first century sustainability because it is warming at a much faster rate than other parts of the world (Meredith et al., 2019; Rantanen et al., 2022). By reducing the frequency and extent of sea ice, climatic warming is acting to open up hitherto inaccessible environments to economic exploitation, including further oil and gas extraction (Kröger, 2023). Although geological knowledge production (‘science’) is still actively working to identify fossil fuel resources in many places around the globe, it is particularly arresting to witness this happening in the Arctic, where the effects of anthropogenic global warming are clear.

Given the importance of the topic, one might imagine that there has been a great deal of research on Arctic oil and gas resources. But it turns out that much of the public discussion about the potential for Arctic oil and gas extraction—either for or against—hinges on the findings of a single scientific study (Wood-Donnelly & Bartels, 2022): the Circum-Arctic Resource Appraisal (or CARA study for short), which was undertaken by

the United States Geological Survey (USGS). The CARA study was published in several stages over about a decade (Bartels, 2024). The first publication was a four-page USGS factsheet titled *Circum-Arctic Resource Appraisal: Estimates of Undiscovered Oil and Gas North of the Arctic Circle* (USGS, 2008). This factsheet presented some striking maps of estimated oil and gas resources and a prominent table listing the size of estimated oil and gas resources in different geological provinces of the Arctic. The factsheet was followed soon afterwards by a high-profile article, ‘*Assessment of Undiscovered Oil and Gas in the Arctic*’, in the renowned academic journal *Science* (Gautier et al., 2009), which presented the results of the study in slightly more detail for an academic audience. Fuller details of the work were eventually published by the USGS as the 30-chapter *Circum-Arctic Resource Appraisal (CARA) Professional Paper 1824* (Moore & Gautier, 2017), with a number of other papers and book chapters appearing elsewhere in the interim (e.g. Charpentier & Gautier, 2011). It is not unusual for full publication of big scientific projects like this one to take many years, but what is striking about this example is that a lot of faith was placed in the initial summaries of the project findings, despite clear (if brief) caveats from the authors that their estimates were ‘based on very scant geological information’ (Gautier et al., 2009).

In the immediate aftermath of the first publications in 2008 and 2009, the CARA study had a remarkable effect in focusing international attention on Arctic resources, as scholars, journalists, industry, and many others outside of geology grappled with its implications. An opposing ‘anti-bonanza’ discourse (Keil, 2014) developed after a few years, partly following disappointing drilling campaigns in the Arctic by companies such as Shell and Cairn Energy, but also later reflecting shifts in governmental energy policy, e.g. Greenland’s decision to stop supporting new oil and gas exploration in 2021.<sup>5</sup> The CARA study has influenced many Arctic policies within and outside the region from 2008 to the present day (e.g. UK Government, 2018; State Council Information Office of the PRC, 2018; Natural Resources Canada, 2022). It is still regularly invoked in high-level discussions of Arctic geopolitics and security and has been widely cited across the natural and social sciences literature, implying that it is seen as a respected and trustworthy source (e.g. Mådje et al., 2022).

<sup>5</sup><https://www.reuters.com/business/energy/greenland-puts-an-end-unsuccessful-oil-adventure-2021-07-16/>

However, on careful analysis, it is clear that the CARA study had many limitations. Making precise estimates of geological resources is difficult at the best of times, and all the more so in a region that had been so little explored by geologists. In the peer-reviewed 2009 *Science* paper, the authors were clear that field data were largely lacking and hence that the project depended heavily on ‘expert opinion’, educated guesswork based on comparisons with geologically similar regions, and statistical methods dealing more with probabilities than with certainties (Gautier et al., 2009). That said, much of this important nuance was contained in ‘supplementary online information’—an extra page-and-a-half of methodological detail, hosted in a separate file on the *Science* website—which would be easily overlooked. The 2008 USGS ‘factsheet’—perhaps a misleading term in itself!—was arguably even less effective in communicating the uncertainties around the data, with only a brief caveat on ‘the wide range of uncertainty inherent in frontier geological provinces such as those of the Arctic’. The factsheet presents its estimates of oil and gas resources in each geological area as single numbers, sometimes to as many as eight significant figures (implying a very high degree of precision), with no indication of the scale of the uncertainty around these estimates—usually a standard requirement of quantitative scientific research. It is perhaps not surprising that the policy-makers and other commentators who read these documents rarely mentioned any caveats at all, instead apparently taking the CARA estimates of oil and gas resources at face value.

The CARA example is far from unusual. For example, Kama and Kuchler (2018) tell a strikingly similar story about the way that shale gas resources have been estimated in Europe, in relation to the controversy around fracking: similar in the sense that even when data are sparse, the very presence of estimates—no matter how unreliable—were enough to spark considerable investment (of time and energy as well as money) on the part of business, government, and NGOs in trying to develop, promote, regulate, and constrain an industry to extract these (real or imagined) resources. It would therefore be useful to understand better how such geological knowledge is produced; who makes it, and for what purposes; how it is communicated and disseminated; and how it gains authority (e.g. through the peer-review process). Scholars in the emerging field of Political Geology are trying to do just that, analysing what Bobette and Donovan (2018, p. 6) call the ‘complex architecture of epistemological practices’ within the geological sciences: that is, the various sets of ways in which individuals or groups of scientists within the discipline produce,

evaluate, and legitimise the claims they make when they generate knowledge. Just as geology permeates politics—think of the struggles between nations to secure access to resources such as fossil fuels, metal ores, and rare earth elements—so Political Geology understands that ‘geologists, with their tools, expedition equipment and teams, are themselves politicians operating in spaces, on behalf of others, and seeking authority’ (ibid., p. 2).

Of course, the fact that scientists make choices about what to study and how to represent the world is important not just in relation to geology, or oil and gas, but is relevant to many (maybe most) of the challenges that humanity faces. But understanding the biases inherent in any area of science is itself a demanding task that requires expertise in at least two areas. In this case, first, we need a solid understanding of the geological science of estimating fossil fuel resources, and the methodologies, approaches, and practicalities involved, if the reliability of the geological data is to be judged effectively. This requires expert natural science knowledge. Second, as geological knowledge emanates mostly from political, and often controversial, places (e.g. government departments responsible for quantifying resources), we need to understand the people producing this knowledge and the networks and environments within which they operate. This requires social science tools and theories. Applying such an interdisciplinary, SD-focused approach to examples such as the CARA study may ultimately help to improve the effectiveness of evidence-based policy development across the whole domain of SD.

### CONCLUSION: HOW SHOULD SCIENCE AND POLICY INTERACT?

This survey of the literature and reflection on our experiences as practising scientists lead us to some tentative conclusions, and many open questions. Perhaps the most pressing is the question about the extent to which scientists should embrace politics. As we have shown, a wide range of positions are held among academics, from embracing the purity of the ivory tower to fully committed ‘scholar activism’. We would suggest that this diversity of positions and strategies is perhaps inevitable and, in its way, a strength: policy-makers can (at least claim to) cite objective science when it is useful, while the most committed scholar-activists drive political change in ways that otherwise might not come about. Nonetheless, it is important to

acknowledge that all knowledge production is embedded within a political context to some degree. It seems sensible for all researchers to be aware of their positionality and of the politics that surround their discipline. Discussion of these issues was not part of the formal scientific training of the present authors, but recent trends towards better consideration of (for example) ethics and ‘decolonisation’ in undergraduate curricula and in researcher training are welcome steps towards more informed science-policy interactions in support of sustainable development. Indeed, increasingly there are funded schemes to allow early-career and established researchers to ‘shadow’ politicians, to be temporarily embedded in policy units, or to undertake ‘knowledge exchange’ fellowships, with the aim of developing scientists who have the skills to bridge the gap between academia and the outside world. Conversely, there have been calls from frustrated scientists for better engagement with science by politicians, and attempts to provide basic ‘scientific literacy’ for politicians (e.g. Sutherland et al., 2013), though it is not clear how effective these efforts have been.

Another trend of interest is the increasing focus on interdisciplinary and/or transdisciplinary research programmes. These attempts to avoid the ‘siloes’ thinking that often emerges in scientific disciplines can help to broaden researchers’ perspectives and enable them to see the wider implications of their work for society. While inter- or transdisciplinary research does not automatically produce more policy-relevant research or more policy-aware researchers, we would suggest that it is a positive step forward, particularly in the context of sustainable development where so many practical issues turn out to have both environmental and social dimensions, which can only be well understood using perspectives from both the natural and social sciences and from within and beyond academia. More balanced policy responses are likely to result if the underpinning research has already considered (for example) the societal consequences of future oil and gas exploitation in the Arctic.

Sustainable Development is fast becoming a key focus for academic research. What is a university for in the twenty-first century, if not to help global society to face its most pressing—indeed existential—challenges? SD often focuses on practical solutions to practical problems, and from that point of view, effective science-policy interaction is critically important. Policy-makers need new concepts and instruments, and they need to be able to justify their policy proposals using sound, evidence-based arguments. The imperatives of SD are in turn shaping the research that is done in our universities, driving funding calls and research programmes in every

discipline from the natural sciences to the arts and humanities. That does not mean that all research needs to be ‘applied’ or policy-relevant: there will always be a need for ‘blue-skies’ research that explores new horizons with no immediate application in sight (ultimately, that is often where new concepts come from). But the process of sustainable development, focused as it is on urgent action and articulating (e.g. through the UN SDGs) a broadly agreed set of societal goals, is itself increasingly shaping research priorities and the boundary between science and policy.

### EXPLORE, REFLECT, AND PRACTISE

- The kinds of evidence that are considered appropriate to support policy development appears to be gradually widening, for example with the increasing incorporation of ‘traditional ecological knowledge’ into the policy process. What might be the advantages and challenges of this increasing inclusivity?
- What are the potential pitfalls of ‘scholar activism’, both for society at large and for the scholars themselves? What are the potential gains?
- Should scientists be better educated about policy, or should policy-makers be better educated about science—or both? Think about your own educational background in this respect. How have you balanced depth and breadth? What would you change about your training, given the chance?

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