Environmental Health Research: Identifying the Context and the Needs, and Choosing Priorities

George Morris, Marco Martuzzi, Lora E. Fleming, Francesca Racioppi, Srdan Matic

Summary

Adequate funding, careful planning and good governance are central to delivering quality research in any field. Yet, the strategic directions for research, the mechanisms through which topics emerge, and the priorities assigned are equally deserving of attention. The need to understand the role played by the environment and to manage the physical environment and the human activities which bear upon it in pursuit of health, wellbeing and equity are long established. These imperatives drive environmental health research as a key branch of scientific enquiry.

Targeted research over many years, applying established methods, has informed society's understanding of the toxic, infectious, allergenic, and physical threats to health from our physical surroundings and how these may be managed. Such, essentially hazard-focused, research continues to deliver policy-relevant findings while simultaneously posing questions to be addressed through further research. Environmental health in the 21st century is however confronted by additional challenges of a rather different character. These include the need to understand in a better and more policy-relevant way, the contributions of the environment to health and equity in complex interaction with other societal and individual-level influences (a so-called socioecological model). Also important are the potential of, especially green and blue natural environments to improve health and wellbeing and promote equity; and the health implications of new approaches to production and consumption, such as the circular economy (WHO 2018).

Such challenges add breadth, depth and richness to the environmental health research agenda, but when combined with the existential and public health threat of humanity's detrimental impact on the Earth's systems, they entail a need for new and better strategies for scientific enquiry. As we confront the challenges and uncertainties of the Anthropocene, the complexity expands, the stakes become sky-high, and diverse interests and values clash. Thus, the pressure on environmental health researchers to evolve and engage with stakeholders and reach out to the widest constituency of policy and practice has never been greater, nor has the need to organise to deliver.

A disparate range of contextual factors have become pertinent when scoping the, now significantly extended, territory for environmental health research. Moreover, the challenges of prioritising among the candidate topics for investigation have scarcely been greater.

Keywords: research context, transition, priorities, policy, social and ecological complexity

Introduction

Environmental health research matters for population health, wellbeing and equity. It aims to establish the short, medium, and longer-term impacts of environmental exposures, and to uncover approaches which can be applied to mitigate and manage them. Moreover, it is

frequently publicly funded, has policy-relevance, and often operates in contested territory with its conduct and outputs a focus for political attention.

Four elements of context appear especially important for environmental health research. The first is, quite simply, the reality of change. All activities targeting population health must be planned and conducted with reference to very dynamic circumstances. Recognising the processes which continuously shape and reshape the foundations for population health and health equity is the stepping off point for all public health activity. This is a message with particular resonance for those who research and manage the relationship between the physical/natural environment and human health and well-being in third decade of the 21st century.

The second crosscutting element of context is characterised as a crisis in science itself. The crisis which, for some, undermines the credibility of science and scientists, has multiple origins extending far beyond the domains of public health or environmental health research, yet each is affected by it. All scientists have a vested interest in the quality of their collective outputs, how they are valued, and how they are communicated.

The third element of context is the international policy context dominated by the United Nations Sustainable Development Goals (SDGs) (United Nations, 2015). The SDGs emphasise the connectivity among many policy agendas, and importantly for environmental health research, the inextricable linkages among environmental sustainability at a global level and health, wellbeing, and equity between and within countries. Environmental health research which recognises the global challenges and the connectivity of local and global policy agendas can facilitate delivery of the SDGs but is also uniquely challenged by them.

The final element of context relates to "mechanisms of exclusion and selectivity" discernable across the wider fied of public health. Several such mechanisms are identified which are especially important in the domain of environmental health research. This article is coloured throughout by a conviction that the simultaneous delivery of health and wellbeing, equity, and environmental sustainability in a multivariate world, ultimately demands a commitment to complex systems research (Rutter et al, 2017).

Given the inherent challenge of complex systems research, it is perhaps unsurprising that it has not been widely deployed in public health. Yet, among the public health disciplines, environmental health and its research base, have adhered particularly closely to narrow, compartmentalised perspectives. This is especially regrettable at a time when the rhetoric and debate across public health have been suffused by references to a richer and more complex environmental contribution, to complexity in the determinats of health and disease and the need to embrace it. Failure to frame challenges in environment and health with reference to a wider set of issues which bear upon them blunts the policy relevance of many research outputs.

Nevertheless, while accepting that they are unable to support the complex systems research to which public and environmental health must ultimately aspire and fully cognisent of their shortcomings, there remains a role for enlightened application of essentially linear conceptual models in public and environmental health. Specifically, they can still be effective in framing issues, guiding thinking, and shaping policy (Morris et al, 2006; Reis et al, 2015; van der

Vliet et al, 2018). Such tools are insufficiently exploited in highlighting research needs, data deficits and policy opportunities.

The product and process of applying linear models to public health issues and challenges can involve affected communities and other stakeholders in identifying and understanding environmental health research priorities. Going forward, community engagement and involvement are essential in addressing the complex environmental health challenges in the 21st Century.

Elements of Context for Environmental Health Research

1. The reality of Change

Two distinct categories of change are important for all of public health and its research base. The first is the large-scale long-term **transitions** at the level of society which, in combination, act on the direct material, social and cultural, and biological conditions which shape human health and wellbeing (Rayner and Lang, 2012; WHO, 2017a). Some of the transitions presented in **Figure 1** have been underway since the inception of the modern public health movement in the early 19th century whereas others are very much phenomena of the late 20th and early 21st centuries.

The '*urban transition*' (the move from rural to urban-based existence) is long established, global, and ongoing; similarly, an '*energy transition*' (incremental substitution of renewable human and animal power by the combustion of finite fossil fuel reserves) has been transformational for society and for population health over more than 150 years. In addition to climate implications of energy transition, we point also to indirect impacts on the organisation of the labour market and the growth in mass private transportation. As the unintended negative consequences of energy transition have become more apparent many countries are of course, seeking to reverse reliance on fossil fuels.

A '*nutritional transition*' (changing patterns of nutrition towards large amounts of highly processed foods and reducing levels of physical activity) has been a societal phenomenon in the West and is now spreading globally from, perhaps, the 1980s onwards.

The '*epidemiological transition*' (the reduction of infectious diseases and the increase of chronic disease as a proportion of the total disease burden) unquestionably alters the context for public health/environmental health activity; yet it is manifestly a product of the complex interactions among many other 20th century societal transitions. Prominent among these has been a '*demographic transition*' (characterised by an ageing population and lowering of the birth rate in many countries). Rayner and Lang (2012) observed that "*No transition can be seen in isolation, it is their totality that matters and that gives public health its complexity"*. The need to navigate effectively in this complexity is discussed at intervals throughout the text.

However, perhaps the most pervasive and fundamental transition for the generations alive in the 21st century and yet to be born, is the '*ecological transition*' - the move from the Holocene to what some authors have termed the Anthropocene (Crutzen, 2006; Rayner and Lang, 2012). In its starkest terms, human activity is damaging, often with irreversible impacts, the global systems on which we rely for health, wellbeing and, ultimately, existence as a species. This ecological damage has gathered pace with the other transitions, particularly population growth and industrialisation.

In the space of 200 years, through our activities and over-use of resources, humans have driven major health-relevant changes at the planetary level.

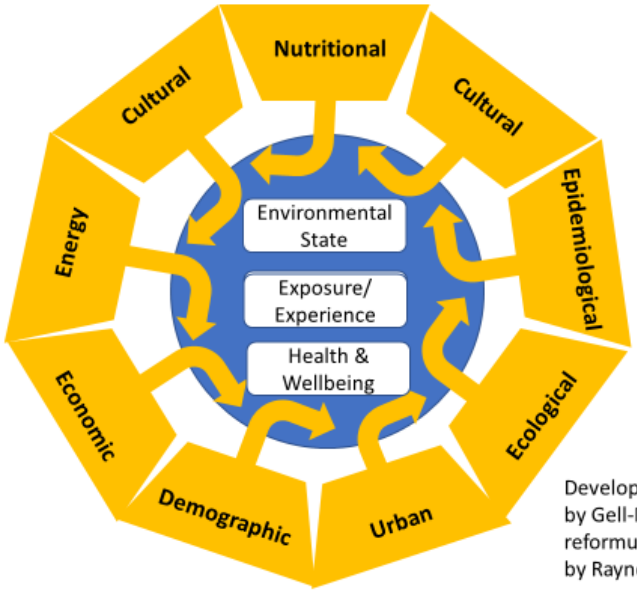
In 2015, revisiting earlier work (Rockstrom et al, 2009), Steffen and colleagues (Steffen et al, 2015) proposed that, to keep the Earth hospitable, humans must live within nine specific limits or 'planetary boundaries' related to biophysical sub-systems and processes. By 2015, four such boundaries had already been crossed. These were: climate change (the highest profile and most immediate threat); the loss of biodiversity; anthropogenic changes to the biogeochemical cycles of nitrogen; and land use changes, including deforestation. Changes in these areas breach the 'safe operating space for humanity', not least because the affected systems, connected in various ways, are very likely to respond in a non-linear fashion.

The situation has profound implications for environmental health research, particularly because the links between environment and human health must henceforth be understood and addressed on vastly extended temporal and geographical scales. No longer can society and individuals hold to the notion their economic and social activities, and their health and well-being, are somehow independent and distinct from the global ecosystem. This recognition lies at the core of the *ecological transition* (Whitmee et al, 2105) and underlies the foundation of the innovative 2030 Sustainable Development Agenda.

All countries, and certainly those in Europe, recognise the health implications of evident and predicted changes to their local or 'proximal' environments exacerbated by climate change. One striking example is the threat to the very physical existence of several island-states from climate induced sea-level rise. Moreover, there is a need to accept that damage inflicted to local ecosystems, to which all contribute, impacts places far beyond national borders, threatening the livelihoods and health of both lands and populations which may appear remote. Additionally, in a world connected environmentally, economically and socially, environmental change anywhere will impact on health, wellbeing and equity faraway as a result, for example, of migration and food insecurity (Morris et al, 2015; 2017).

Appreciating the importance of these distal pathways of ecosystem damage to human health and well-being and equity demands a greater understanding of the connectedness of life, including human life, on Earth. Such notions chime with Darwinian and other 19th century perspectives e.g. von Humboldt (Meinhardt, 2018) and indeed the scholarly traditions of non-western civilisations but eroded over time by a cocktail of positivism, human development, and a naïve faith in technology. Full appreciation of the global connectivity of social, economic and ecological systems also implies a more realistic view of so-called "natural services". Here, humanity is not simply a recipient of the benefits, but also charged with securing the stability and sustainability of natural systems and processes. The implications for environmental health research, broadly defined, are huge. It is now inconceivable that health, well-being, healthcare, or equity in any of these domains, can be delivered without articulating an environmental conceptualisation of public health for the 21st century (Adger et al, 2009; Rayner and Lang, 2012; Morris et al, 2015).

Figure 1: Important societal and global transitions reshaping



Developed from ideas articulated by Gell-Mann (2010) and reformulated for public health by Rayner and Lang (2012)

From a specifically environment and human health perspective, all transitions (singly and in joint interaction) matter because they have the potential to act, often simultaneously, upon the state of the physical environment, the nature of individual exposure to that environment, and the individual's vulnerability/sensitivity to environmental exposures (WHO, 2017a). The transitions in question vastly outpace possible evolutionary responses by humans or many other species, thus putting the health of multiple species and ecological systems under additional pressure (Vineis, 2017). For example, a revolution in the use of chemicals and the widespread use of plastics (a subset of a broader scientific/technological transition) has transformed the proximal physical environment everywhere, and the nature of human exposure to it. At the same time, our increasing body burdens of anthropogenic chemicals amend individual vulnerabilities, and may be related to increases in the incidence of non-communicable diseases. The true impact of the chemical revolution on global ecosystems, especially ocean health, is now becoming clear (Landrigan et al, 2018)

A second, rather different, type of change, sometimes driven by the research effort itself, is the evolution of ideas which shapes not only the understanding of how health and wellbeing are created and destroyed; but how, and when, society can or should intervene. The term 'ideas' is used loosely in this context to include not only ideas and insights immediately related to the interface of the environment with human health but, more broadly, to include causal paradigms concerning health and disease, and, more broadly still, societal values and norms.

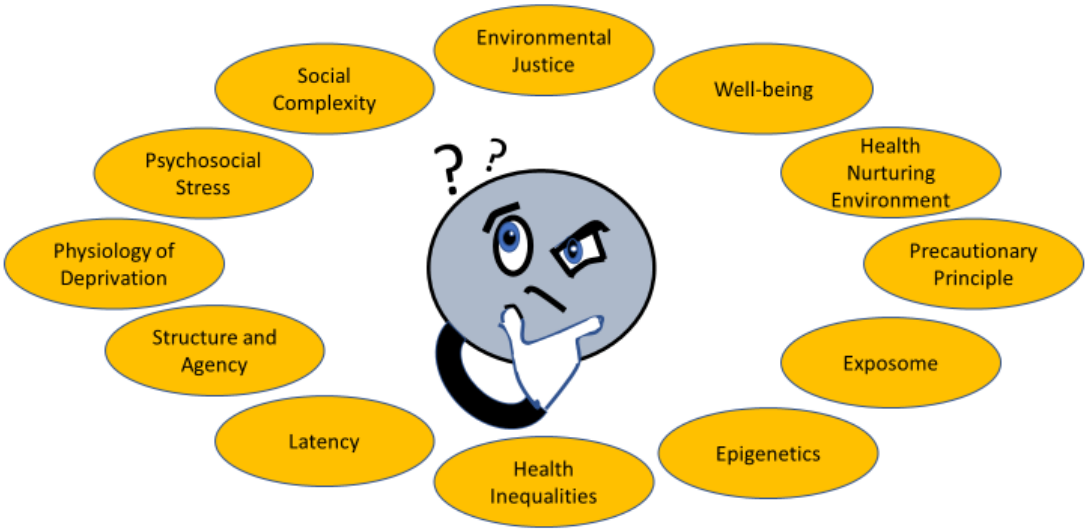
In adopting the term an '*evolution of ideas*' as a major dimension of change in public health and environmental health, it is necessary to recognise how ideas may evolve, but can also change quite quickly in response, say, to an unexpected event or discovery. Thus the discovery of the contributory role of *Helicobacter pylori* in the pathology of stomach ulcers was a discrete discovery of immediate significance to the diagnosis and treatment of a specific disease, but actually nurtured the evolving idea that several diseases of, presumed, non-infectious aetiology (see epidemiological transition, above) may actually have microbial

underpinnings, as seen in the association between Human Papilloma Virus and cervical cancer, and medical solutions, such as vaccination (Francesci & Campisi, 2014).

Figure 2 highlights some of the ideas which have become significant for the field of environment and health and are, by extension, important in setting and prioritising within the environmental health research agenda . Those illustrated in **Figure 2** are indicative, rather than comprehensive.

Thus, for example, understanding of latency (a time lapse from initial exposure until development of health effects) is included. The appreciation of latency is traceable especially to ideas emerging from cancer epidemiology in the 1950s . Also included in Figure 2, are the concepts of 'epigenetics' (the way in which environment influences gene expression) See, for example, Berger et. al. (2009) and 'the exposome' (a concept complementary to the genome and intended to capture the influence of all human exposure from conception onwards). See, for example, Wild, (2005). Further iterations of Figure 2 might equally include the life-course perspectives on environmental exposures and outcomes, of particular relevance to air pollution and health, which have gained traction in the 21st century (Royal College of Physicians, 2017). .

Figure 2: The Evolution of Ideas
(These are a mix of concepts, principles, norms, research insights etc. which influence how society understands and approaches the environment and health issues)



Thus, a function of environmental health research is to understand societal-level transitions, their impacts on, and the implications for, the health of both the environment and human populations. But it must also be about developing and testing ideas that are relevant to the relationship of the "health" of the environment to human health and wellbeing, the management of that relationship, and the process of informing the translation of validated ideas into policy.

An especially challenging 'idea' for the whole public health community and public health research in the closing decades of the 20th century was the recognition of social complexity in the determinants of health. Often termed "*the socio-ecological model of health*" (Evans and Stoddart, 1990; Dahlgren and Whitehead, 1991), this presents health and disease as emergent products of a complex interaction of societal-level factors (including the physical environment), with characteristics specific to the individual (including genetic predisposition and individual behaviour).

In the 21st century, this already hugely complex public health challenge has been overlaid by a further layer of complexity stemming from the recognition of the health/wellbeing and equity implications of humanity's impacts on the natural world (Rockstrom et al, 2010; Steffen et al, 2015; Rockefeller Foundation-Lancet Commission on Planetary Health, 2015). This latter development catapults the environment to the heart of the public health agenda, and vastly extends the temporal and spatial scales for environmental health activity and impact.

2. A Crisis in Science and Policy

A further aspect of context with arguably more diffuse impacts on environmental health research is a perceived crisis in science itself. Human development over the last 200 years has been heavily dependent on scientific advance; evidenced by countless instances where science has supported and driven human progress and continues to do so. For example, the exponential growth in global population was founded on a dramatic increase in food and energy production enabled by science and technology. Yet, for many, the celebration of the achievements of science is coloured by talk of a 21st century "crisis in science," and the need to understand and address its causes. An effective response is essential if society is not to blunt its most important tool to address the huge challenges which lie ahead (Casadevall and Fang, 2015). The environmental health research agenda, in embracing biology, chemistry, the earth sciences, medicine, public health, and a spectrum of social sciences, is greatly affected by the generic problems in science as a whole.

Even a brief overview of the literature highlights three non-mutually exclusive dimensions to a crisis which manifests as a diminution of public trust in science, its institutions and those bodies (including governments), that utilise its outputs.

An important dimension of the crisis relates to **reproducibility**. This, alongside peer review, is a key mechanism by which the validity of scientific advance is ensured. Yet, scientists can find it difficult or impossible to reproduce the results of their own scientific studies or those of others (Baker, 2015; Open Science Collaboration, 2015; Casdevall and Fang, 2015; Saltelli and Funtowicz, 2017; Fielden, 2017). Neither is it irrelevant that multiple repetitions of studies in an effort to demonstrate reproducibility can involve significant cost. Concerns over reproducibility go right to the heart of the scientific process, and contribute to a situation in which the credibility of scientific findings is increasingly questioned. This is especially relevant as humanity steps into the uncharted territory of the Anthropocene, where the familiar Popperian approach of hypothesis testing may itself become increasingly inadequate. Indeed, the legitimacy of conducting experimental or observational studies by deploying the "ceteris paribus" concept may be increasingly called into question.

Another, closely related, dimension of the crisis concerns science's own internal systems of **governance**. Here, the critique takes various forms. Some suggest the systems which have

long secured quality and rigour are casualties of perverse incentives and "hyper-competition" for inadequate funding, promoting a drift in emphasis from rigorous repeatable research to "flashy high impact studies" (Casadavell & Fang, 2015). Unfortunately, in some cases, the findings of these high-profile studies are later shown to be exaggerated or erroneous resulting in reputational damage to all science and scientists (Saltelli and Funtowicz, 2017; Casadevall & Fang, 2015).

Science's underpinning peer review system also attracts criticism (see, for example Schroter et al, 2008; Morey et al, 2016), as does the role of metrics such as the journal impact factor which are seen as inappropriate surrogates for research quality (Morey et al, 2016; Ioannides 2014). Wilsdon (2015) makes a plea for a more nuanced approach to metrics, a theme echoed in the review of the UK's Research Excellence Framework (Stern, 2016). Ravetz (2016) even implies an inherent incompatibility between the use of a scientific methodology to pursue good governance in science and actually achieving it. In essence, this is because individuals and organisations may actively seek ways to manipulate such methodologies in their own interests. Expressed in another way, the process may be gamed (Wilsdon, 2015).

A response to a crisis of reproducibility and governance seems likely to lie in changes to the current culture within science. Here, the key actors in what must be a multi-pronged approach are likely to be the funders, the institutions, the journals, and the researchers. It has been observed by Dame Ottoline Leyser, Director of the Sainsbury Laboratory at the University of Cambridge, UK that the reproducibility difficulties are not about fraud but rather *"a culture that promotes impact over substance, flashy findings over the dull, confirmatory work that most science is about"* (Leyser, quoted in Feilden, 2017). However, at the same time, the pace at which technology evolves and penetrates markets (e.g. the rapid evolution of mobile communication) and calls for decisions to be made rapidly, are at odds with the time required to accumulate a valid set of repeated results to complement the evidence-base. In contrast, "the need for more research" has often delayed decisions to intervene, which in the end have resulted in public health damage (European Environment Agency, 2013). Ambient air pollution and climate change are cases in point.

The development of the "precautionary principle" stands here as a remarkable example of how the policy and scientific communities have attempted to navigate this dilemma. The challenge over repeatability is certainly urgent because the unease generated by a belief that science's outputs are unreliable, ripples out to research funders, editors, publishers, and beyond to taxpayers, NGOs and citizens themselves (Saltelli and Funtowicz, 2017). Moreover, because much of environmental health research is publicly funded, it important that resources are not wasted and where public benefit is derived that it is properly communicated (WHO 2017a;2017b; WHO, 2019a).

If the first two dimensions of science's crisis, reproducibility and governance, are seen as challenges to all of the scientific community, the third, relating to the **use of science for policy** and the closely interwoven concept of evidence-based policy, has particular resonance for the increasing number of scientists whose outputs are targeted towards a political/policy audience. This is not least because funding relies heavily on the value which society and policymakers attach to their outputs. This is frequently the situation where public health, including environmental health research, is concerned.

In thinking about the relationship of science to policy, it is useful to distinguish between so-called *regulatory Science* and *academic Science*, a differentiation proposed by Jasanoff

(1990) and refined by Dohler (2012). Academic science is characterised as a curiosity-driven activity, open-ended in timescale and initiated by scientists themselves. Its goal is to yield "truths of originality and significance". In contrast, regulatory science is policy-driven, initiated by government or its agencies with the purpose of yielding "truths relevant to policy", often within an imposed timeframe (statutory, political, legal etc.). It is clear that environmental health activity can be informed by both regulatory and academic science.

Among several important reflections made on concluding her tenure as Chief Science Policy Adviser to the European Commission, in 2014, Professor Dame Anne Glover made a plea for the Commission to separate the political imperative from evidence-gathering processes (Glover, quoted in Wilsdon, 2014). Professor Glover seemed to be echoing a familiar worry in the scientific community that evidence-based policy can all too easily become policy-based evidence with undesirable consequences.

At least for what has been characterised as regulatory science, it might be supposed that an inevitably close connection between the political and the scientific spheres could generate situations where a complex body of scientific literature is selectively culled, or funding is found for new studies to identify evidence in the support of regulatory decisions, while downplaying contradictory evidence [Johnston (2012) quoted in Strassheim & Kettunen (2014)]. Professor Glover's solution, in essence a "demarcation model" which separates science from non-science (Funtowicz, 2006) is frequently proposed, well-motivated and an ostensibly logical bulwark against science 'dancing to the tune' of policy makers. However, the model can be challenged on grounds of viability (Saltelli and Giampietro, 2017, Strassheim & Kettunen, 2014).

Intuitively, the more complicated and controversial the problem, the less easy (or perhaps even desirable) it becomes to separate risk assessment and risk management or science from policy (Rittel and Webber, 1973 quoted in Strassheim and Kuttenen, 2014). It has been observed that problems encountered by public health and its research base, including environmental health research, are often exceedingly complex or "wicked". Wicked problems resist resolution through simple or single interventions; and evidence of different types from widely differing sources may be relevant when understanding the problem and seeking solutions. Even when attempting to frame wicked problems, value free facts may be scarce, introducing the potential for bias. Such influences may be neither recognised nor acknowledged. A further complication for environmental health research, when it is regulatory, is its obvious concern to inform both risk assessment and risk management, i.e. it has a foot in both camps.

Other related concerns about the science-policy interface centre on disquiet over the very concept of evidence-based policy. Although, well established in its own right, evidence-based policy in the health field has its roots in ethically-driven work to introduce evidence-based medicine. From its inception, evidence-based medicine was underpinned by the systematic review of (primarily) randomised controlled trials (RCTs) (Pearce et al, 2014) with their exalted status as the experimental design considered most likely to deliver objective value-free evidence. Medicine is of course exceptional in its opportunity to conduct and exploit the products of RCTs. Other branches science and public policy often operate in altogether messier, less controlled and less controllable territory, thus limiting or denying the possibility to conduct or exploit RCTs.

Instead, policy in the wider health field usually relies on the synthesis of evidence of different types - a so called "mixed economy" of evidence (Petticrew et al, 2004) which includes components with rather lower status in accepted medical evidential hierarchies. This is inevitable and not, of itself, a criticism of the evidence or those who generate it. Intuitively though, it implies a need for a less technocratic or absolutist stance from the advocates of evidence-based policy.

Yet, Saltelli and Gampietro (2017) observe that one of the critiques of evidence-based policy is, precisely, its technocratic stance and apparent disregard for the power relations which inevitably exist at the interface of science and policy. A more cynical, or possibly sinister, critique of evidence-based policy, again from Strassheim and Kettunen (2014), is that "*evidence-based policy is used instrumentally to neutralise ideologies and hide power asymmetries from decision making*". This would seem to be a point at which evidence-based policy becomes policy-based evidence.

Another critique is that in real life "evidence-based" policy is something of an illusion, since policies are developed within a complex social, cultural, political, and economic context, with an unequal distribution of negotiation and representation power. In turn, these factors exert a strong influence on the final outcome of the decision-making process, to the point that many now prefer to speak, perhaps more realistically, of evidence-informed policy making.

3. Policy Context

The policy context for environmental health activity, including environmental health research, in any specific country at any time, is dictated by prevailing political, social and economic conditions. The environmental health problems experienced by a country's citizens and the priorities identified by governments are likely to be closely aligned to that country's stage of development.

Thus, there is considerable heterogeneity in terms of environmental concerns, health and wellbeing impacts, policies, and governance. However, all countries share a common 21st century environmental health research agenda around for example: a) sustainable development; b) recognition of the role of cities as key places for health; and c) environmental health inequalities (WHO WHO 2012a; 2012b). Together, these and other shared concerns imply a strong international dimension to environmental health research. This is especially so, with the all-pervading threat from to health and wellbeing from the deterioration of the Earth's biosphere and climate.

While recognising the importance of national and regional policy instruments, two particular elements of international policy are of general relevance in the field of environmental health research. The United Nations 2030 Agenda for Sustainable Development was introduced in 2015 with 17 aspirational Sustainable Development Goals (SDGs). The SDGs and their 169 related targets apply to all countries, presenting a truly global agenda and covering a broad range of necessarily interconnected development issues, including: health and wellbeing, poverty, hunger, education, water, energy, and climate and other environmental change.

The SDGs are deliberately framed to be universal, integrated and transformative; and there is a clear commitment to addressing inequality in their delivery - the idea of no-one left behind. New ways of working and unprecedented integration and co-operation within countries and internationally are central to implementation of the SDGs. It is also important to note that, just as health is a determinant, an enabler, a key component and an outcome of all the SDGs,

efforts to create health through securing a healthy and sustainable environment can drive progress towards all of the SDGs.

A second important element of the international policy is the New Urban Agenda (United Nations, 2016). This recognises the critical role of cities in achieving sustainable development, reiterating a commitment to interlinked, social, economic and environmental principles, and rethinking the way we build, manage and live in cities. A novel aspect of the NUA is its commitment to what might be seen as a type of "subsidiarity" – a recognition that, while national governments play a leading role in the definition and implementation of effective urban policies, sub-national and local governments; civil society and other stakeholders play a no less important role.

The NUA is obviously an indication of a high-level recognition of the importance of urbanisation and its implications for health and wellbeing in the here and now; but also that how we shape our cities has implications for sustainability and human capacity to deliver health, wellbeing, health care, sustainability, and anything approaching equity in these things going forward. Much of this is about recognising that how cities operate, and how we live, move and consume within them, impacts the proximal physical environment and global ecosystems in health-relevant ways.

Cities have been key theatres for environment and health activity for much of the modern public health era and emerge once again as the frontline in the battle to achieve sustainability, and to protect and improve human health and equity. The articulation of the NUA with the SDGs and, within a European Regional context, the principles and aspirations of the European health policy framework, Health 2020 (WHO, 2012a) is striking.

4. Mechanisms of Exclusion and Selectivity

Strassheim and Kettunen (2014) have argued that public policy "*rests on its own mechanisms of exclusion and selectivity*". Given its complicated but often close relationship to public policy, it is useful to consider the mechanisms of exclusion or selectivity which might exist in the area of environmental health research. If environmental health, and by extension its research base, are predominantly narrow, hazard-focused and compartmentalised (Morris et al, 2006), this might reasonably be linked to a failure to acknowledge such mechanisms.

Examples of exclusion and selectivity mechanisms which have a bearing on the conduct of environmental research are summarised in **Boxes 1-4**. It is notable that each might be viewed as a means, consciously or unconsciously adopted, to manage or navigate within what is often bewildering complexity. Yet, viewed from another perspective, each is a mechanism of exclusion or selectivity which exerts influence on the process of research and the questions it seeks to address, reducing the policy relevance of its outputs.

Box 1. Adherence to Linear approaches in Issue Framing

Environmental health researchers are part of a public health community which for 40 years and more has been accepting of the idea that the determinants of population health and equity are socially complex. Yet, very simple, arguably 'simplistic', linear models of cause and effect still regularly underpin and inform activity in public health, especially the sub-discipline of environmental health. Here, they are used to frame issues, to generate research questions and to guide interventions.

Rutter et al (2017) are among the more recent commentators calling for a move towards complex systems research in public health -"The *identification, implementation and evaluation of effective responses to major public health challenges require a wider set of approaches and a focus on complex systems".* We consider that the continued application of linear models of cause and effect to frame and address contemporary public environmental health challenges is inevitable, pending the emergence of more sophisticated approaches. While recognising these conceptual models will always be very simplified representations of complex realities, it is important that they are not simplistic.

The failure to truly confront complexity, whether socioecological or generated by ecosystem damage, is understandable, but qualifies as an exclusion mechanism and creates a worrying disconnect between public health's dominant causal paradigm and the modes of enquiry we habitually adopt.

Box No2 Black Box Epidemiology

Well-intentioned efforts of the epidemiological community to 'deal with' the social complexity have, themselves, led to what can be seen as a further example of exclusion/selectivity in environmental health research - so-called "black box epidemiology" (Susser and Susser, 1996, Kessel, 2006). Black box epidemiology is a pejorative term used to highlight shortcomings in what is otherwise known as 'risk factor epidemiology'.
Risk factor epidemiology was developed in the post WWII era by exploiting enhanced computing power and statistical advances to better understand the causes of new forms of epidemic disease. The new epidemics of cardiovascular disease and cancers were believed to be of non-infectious aetiology; and were often statistically associated with aspects of individual lifestyle or behaviour (ostensibly freely chosen) and, initially at least, rarely linked in any way to environment.

A particular attraction of risk factor epidemiology lies in its capacity to represent, mathematically, the relative risk of contracting a disease between people exposed to a putative risk and those who are not. Moreover, with methodological advance, it became possible to control for nuisance factors, considered to confound the relationships under investigation.

The contribution of risk factor epidemiology is unquestionable, including for environmental agents and health outcomes (Susser and Susser, 1996; Kessel (2006). Yet the critique of the methodology connoted in the term "black box epidemiology" is also well rehearsed. It has undoubtedly contributed to an individualisation of health status (Morris and Saunders, 2017) and has generally failed to elucidate the societal and environmental factors whose influence and interplay shape the health and health-relevant choices of individuals (Susser and Susser, 1996; Morris and Saunders, 2017).

Co-existing environmental exposures (e.g. air pollution and climatic factors) are the reality, as is the presence of a host of other social, economic etc. influences. The occurrence of synergistic interactions is probably more frequent than implied by assuming risk proportionality. These coinciding factors may be critical in determining the severity and scale of the health impact of the environmental agent under investigation. Thus, for environmental health, as for other domains in public health, the relative risks generated by black box epidemiology are abstractions whose scientific importance may be considerable but whose capacity to inform effective interventions can often be less evident.

Box No 3 Preoccupation with the Proximal

The *ecological transition* was described above as the most fundamental transition for society, public policy and public health. Unsurprisingly, it is also a major contextual influence for environmental health research. This is not least because, in the 21st century, effective research requires potential to identify interventions that offer co-benefits for health and sustainability. Better still, good research may help identify interventions which can deliver a triple win of improved health and wellbeing, greater equity, and environmental sustainability (Staatsen et al, 2017).

Yet a clear danger, going forward, is the risk that, perhaps due to the perceived enormity of the challenge, researchers (and possibly even more, policy makers) will retain a disproportionate focus on ostensibly more manageable 'proximal' threats to health. Such a perspective might cause environmental health research to miss real opportunities to show that actions taken to secure health and wellbeing in any location, if carefully conceived, may simultaneously secure the health of populations living beyond borders and for generations yet to be born. Expressed in another way, a preoccupation with the proximal can be construed as yet another form of selectivity and exclusion in environmental health research (Morris et al, 2017).

Box No 4 – Insufficient Attention to the Implications and Determinants of Lifestyle and Behaviour

An implicit requirement for addressing many of the shortcomings in environmental health research is a fuller and more productive engagement between environmental science, environmental health and the social sciences, not least behavioural science. While there is ample evidence that the public health community in general has ascribed importance to behavioural science in pursuing its aspirations for population health and equity, this is less evident in the field of environmental health. Yet, manifestly, health-relevant characteristics of the environment, the exposure of individuals to it and, to an extent, their vulnerability to environmental exposures are substantially dictated by lifestyle and behaviour.

Importantly, the characteristics of the physical environment are in large part shaped by the behaviours people adopt, primarily as they move and consume. Such issues are explored in a policy context in important outputs from the EU Horizon 2020 funded INHERIT project (see for example Staatsen et al, 2017; van der Vliet et al, 2018). In yet another form of complexity stemming from adaptive responses and feedback cycles, behavioural science also teaches us that the behaviours we adopt are themselves shaped by physical, social and other circumstances. The behaviour of humans and the lifestyles they adopt, and the need to influence these remain dominant concerns as humanity seeks to prevent/mitigate the anthropogenic disruption and degradation of planetary processes and systems and their attendant threats to health and equity.

Choosing Priorities for Research and Action

The elements of context discussed above all have a bearing on the environmental health research agenda, how it ought to be shaped in the future, and the priorities which might be ascribed within it. In taking stock, we draw together dominant themes and highlight their interconnections.

By any interpretation, the existential threat posed by humanity's impact on the Earth's processes and systems, and its short, medium, and longer-term implications for sustainability, health, wellbeing and equity, have pride of place among the issues discussed. Labelled here as the "*ecological transition*" (Rayner and Lang, 2012), but also sitting at the core of, concepts such as ecological public health (Morris et al, 2010; Rayner and Lang, 2012), One Health (Lerner and Berg, 2015; Destoumieux-Garzón et al 2018); and Planetary Health (Whitmee et al 2015), the ecological transition extends the temporal and spatial scale of environmental health activity while injecting unprecedented urgency.

An important function of environmental health research in the 21st century must be to make explicit how changes in global systems and processes impact human health and wellbeing and for whom. For example, environmental health research can further expose the mechanisms by which, in a world connected socially, economically and ecologically, environmental change in one location has potential to impact health, wellbeing and equity in an entirely different location. Such insights will only be achieved if complexity is recognised and a sense of shared ownership and responsibility towards all humanity and those yet to be born is nurtured, Environmental health research can improve understanding and awareness, define the common purpose and, through this, generate pressure for action at all levels.

On a closely related theme, and irrespective of the urgent need to think and act on a global scale, it is necessary to accept that the principal theatre for environmental health activity remains the urban and rural settings where people live out their day-to-day lives. An ecological perspective on the pursuit of population health demands changes to how people live, move and consume in their own communities and neighbourhoods (WHO. 2107a; Staatsen et al, 2017). Here, the state of environment (good or bad) might be usefully viewed as a health relevant component of 'place' – a concept that integrates the social, economic, physical, cultural, and historical aspects of a location which, in combination, generate health outcomes (good and bad) and often reproduces them, generation to generation (Scottish Government, 2011). The message must be that many challenges for environmental health research are, for many practical purposes, confined to the proximal context. Yet, many, ostensibly proximal, environmental health challenges such as ambient air pollution or contamination of coastal waters also have distal dimensions (Morris et al, 2015). Accordingly, the identification and evaluation of local policies and actions which can achieve a triple win in terms of health, sustainability and equity and, in so doing, integrate the proximal and the distal impacts on health and equity, is an essential core for environmental health research in the 21st century (Staatsen et al, 2017).

Complexity in the determinants of health, equity and sustainability, and the need for environmental health research to embrace this, has been another recurring theme in this article. Calls to develop general systems research and complex systems approaches in public health span several decades (see for example, Weed, 1998; Rutter et al, 2017). Yet it is hard to avoid the conclusion that the full assimilation of the systems-based approaches, to which public health logically aspires, remains a rather distant prospect. Researchers in environmental health, and the policymakers and practitioners who are the clients for their

outputs, require protocols to navigate within this complexity to deliver effective, practical responses to everyday challenges and threats and to a unfolding ecological crisis.

When setting out the elements of context in the forgoing sections, it was observed that environmental health research has paid scant attention to human behaviour, its determinants and its consequences. The need to address this deficit in research is brought into even sharper relief by the recognition that, while always important for environmental health as a discipline, how members of the public, business leaders and policy makers behave has a profound bearing on capacity to deliver the triple win (van der Vliet et al 2018).

Each of the themes drawn out in this discussion implies an extension in the scope of historical environmental health research beyond historical and contemporary boundaries. This will involve taking environmental health research beyond the proximal to embrace a distal dimension; promoting new partnerships with social, and especially behavioural, sciences; and challenging researchers to embrace complexity.

Such an expansion will generate new and diverse avenues of enquiry and a commensurately diverse set of research questions. It will also make explicit the need for wide stakeholder engagement. Indeed, a "community of peers", blurring the distinction between stakeholders and scientists, has been proposed as the main avenue for contemporary environment and health research and governance (Funtowicz and Ravetz 2018).

Managing the expansion to ensure that concise well-formed research questions emerge and are brought to the table for funding is likely to be hugely challenging. In discussing the relationship between science and policy, we highlighted a useful differentiation between regulatory and academic research. Academic research, when successful, may illuminate a whole field of study. Research in exposomics or epigenetics can be seen as examples of avenues of academic research but it can also be argued that methodological work in environmental epidemiology to embed complex systems approaches would qualify as academic research.

It is clearly important that both regulatory and academic research feature among the candidate topics for research funding. Yet, devising a single approach which permits meaningful comparison of the relative worth of topics when some are academic, and others regulatory, seems all but impossible. Accordingly, it is only possible to make a plea for a proportion of environmental research funding to be set aside to support academic research (e.g. European Research Council funding). This could be disseminated where there is a reasonable prospect that the research will yield truths of originality and significance with potential to ameliorate the negative impacts and promote the positive impacts of the environment on health wellbeing and equity.

Ostensibly, regulatory research offers more promising territory in which to introduce a structured approach to prioritisation. Its goals are, in many cases more specific and its challenges more readily framed in terms of unambiguous research questions. On the other hand, a research question such as "What are the health, well-being and equity implications of 5G technology? can only be addressed by subdivision into a large set of subsidiary questions. The range and diversity of research even in the regulatory category is potentially huge and might, for example, include purely epidemiological investigations - studies to explore the biological plausibility of associations between environmental exposure and health outcomes; or qualitative and/or quantitative evaluations comparing the efficacy of interventions and

policies. Regulatory research in environmental health often extends into the realms of health and environmental economics (including cost benefit analysis) and much more besides. In summary, it is a very broad church suggesting that while there may be an appetite for greater objectivity in prioritising competing projects, a rigorous, heavily codified, quantitative approach to prioritisation is unlikely to be possible.

Despite these challenges, we suggest an entirely subjective process relying on expert judgement is no less problematic due to the risk of biased, value-laden decisions potentially suffused by conflicts of interest.

While they are vitally important for research governance, the well-established considerations applied when judging the quality of existing or proposed research have only limited relevance when ascribing priority amongst research topics. Whether a research question should be a priority seems to be more a function of: 1) whether the question targets a significant gap in knowledge; and 2) whether health and wellbeing, sustainability, and equity within a particular population or geographic area are likely to benefit, directly or indirectly, from addressing that gap in knowledge (health/sustainability/equity impact).

When asked what might matter when judging the relative importance of different environmental health topics, respondents may for example cite the number of people who are affected by the exposure, the severity of the effect and, perhaps, the strength of evidence linking exposure to the effect. These three factors are relevant considerations in classic risk assessment and are notionally quantifiable. However, these criteria are more about judging the importance of an environmental health issue in isolation, than they are about judging the priority for research relating to that area.

In ascribing priority, respondents (particularly policymakers) might also cite the level of public concern over an issue. Such considerations are the subject matter for an important literature relating to the social construction of risk. It may be sufficient here to observe that, where something is socially constructed, it is less likely to be amenable to the application of pre-set quantitative criteria.

Commentators might also cite the likelihood of achieving a successful intervention as very important in deciding whether research funding should be directed to a problem. If a problem seems wholly intractable, or the levers of change inaccessible, then this may lead to a perception that funds would be better directed elsewhere.

All the above factors seem important when prioritising environmental health research. The overarching point however is that in any proposed list of prioritisation 'criteria,' some will be, at least notionally, quantifiable while others will certainly not. One criterion in particular seems to challenge this strict dichotomy by being in some dimensions quantifiable but in others very unlikely to be so. It would seem a gross omission when thinking about research priority in environmental health to disregard the potential of research on a topic to reduce inequality.

In 2012, the WHO European Centre for Environment and Health published a comprehensive Report on environmental health inequalities in the European Region (WHO, 2012b), A second report (WHO, 2019b) has subsequently been published offering furher and more detailed insights into the nature and magnitude of environmental health inequalites across Europe was published in 2019. The Reports present information linking health-relevant

environmental exposures to social variables; and contain a useful reflections on the concept of environmental health inequalities. Yet, despite their contribution in an important area of environmental public health, an unavoidable conclusion is that those deciding on the importance of a research area will often fall back on a value-judgement about inequality. Here, concepts of fairness and the distribution of costs and benefits over space, time, socially, and over generations are pertinent, but definitive information may be limited. However, if the pursuit of the "triple win" is an important goal for environmental health research, understanding the inequalities impact is important.

In the light of the above, the notion of criteria for prioritising among research areas and goals in environmental health demands further exploration. A set of strict criteria which could be systematically applied, although intuitively attractive, could be an impediment to the progress of the environmental health discipline, and diminish its societal value. Algorithm-based approaches such as those deployed in decision-support tools would hardly apply, as the wide range of research questions and methodologies through which such algorithms might be addressed is frankly bewildering.

On the other hand, a carefully devised set of dimensions, concepts or considerations to which it is useful to have regard, might usefully guide professional judgment when ascribing priority in environmental health research, helping to identify most profitable goals, while increasing transparency and accountability. The process of evaluating candidate research topics in terms of concepts would never avoid an element of subjectivity or deny a proper role for professional judgement, but the process would become broadly transparent and those involved would be implicitly challenged to strive for objectivity and consistency. There is a precedent for such an approach to evaluation in the celebrated work of Professor Sir Austin Bradford Hill in the concepts (often misused as stringent criteria), he proposed for consideration when differentiating between causality and association in the field of epidemiology (Hill, 1965).

It has been implied that framing environmental health issues in a more holistic and enlightened way can help identify the gaps which might become targets for a modern, prioritised environmental health research agenda. Issue framing, especially in a multi-stakeholder context, can reveal gaps in knowledge, and information in the form of data and policy (Morris et al, 2006; Scottish Government, 2008). Furthermore, engaging multiple stakeholders in identifying the contexts, gaps and potential priorities can address some of this complexity, and forge new collaborations and approaches. By extension it can be useful in orientating the research agenda. (Morris et al, 2006; Reis et al, 2015; van der Vliet et al, 2018)

Conclusions

Many of the challenges in environmental health will ultimately be better understood and addressed through systems-based research

Throughout this article, an underlying tension has been emphasised between adherence to linear models of cause and effect, and the epidemiological demands of a complex multivariate world. By no means exclusive to environmental health, this failure to confront complexity means that environmental health research and its outputs can lack utility in real world situations. The message, most recently and eloquently set out in Rutter et al (2017), is that public health as whole must move rapidly to develop systems-research. This necessarily

implies the development and support of a new generation of scientists, researchers, civil servants, and policy makers. This new generation must be exposed to transdisciplinary and trans-sector complex system thinking early on and throughout their academic and professional training.

Many dimensions of environmental health research will continue to lack real world relevance or traction without an understanding of the role, implications and determinants of behaviour in an Environmental Health context

Modifying human behaviour in environment and health is self-evidently challenging, and, in this regard, it is natural to think first of the behaviour of the general public. Yet, the behaviour of policymakers and those who execute policy is no less important. The need to understand and intervene to secure of behavioural change, including for policymakers, has now generated a very significant literature [See for example Michie et al. 2011). Indeed, the National Institute for Clinical Excellence has compiled advice on general approaches to health-related behaviour change (NICE, 2007).

There is a strong case for greater engagement between environmental health and behavioural science. Nowhere, is the need to understand and modify the behaviour of policymakers and the citizenry more evident than in relation to the environmental damage already undermining health and wellbeing, sustaining inequalities, and creating an existential threat for humanity.

The dynamic nature of environmental health implies that any functional protocol for prioritising environmental health research must be supported by horizon scanning

Long-term, large scale "transitions" operating at the level of society in combination with a continual "evolution of ideas" generate a dynamic context for environmental health research. This implies a need to keep the environmental health research agenda under continual review. It is hard to conceive of a functional system for identifying and prioritising research needs which does not embody a structured approach to horizon scanning. There is a considerable literature on horizon scanning in the domain of public health, see for example Schutz (2006; van Rij, 2010)

The scope of environmental health research in the 21st century must extend beyond proximal, and often quite fundamental issues such as air quality or sanitation, to the implications for health, wellbeing and equity of human-driven changes to global ecosystems

The public health, equity and existential significance of the ecological transition, the fact that humans are now damaging planetary processes and systems while consuming resources at an unprecedented rate, is profound. Thus, while it is vital not to lose focus on proximal issues, it is important to identify and evaluate polices which can secure health and wellbeing while simultaneously securing global systems and processes.

These include policies and actions that offer what are known as co-benefits or, better still, policies which deliver health and wellbeing, sustainability and enhanced equity - a triple win. Such policies and actions are key to avoiding the social, economic and health consequences of the unsustainable ways in which we as a society currently live, move and consume. Well considered interventions in the fields of energy, transport and agriculture show particular capacity to deliver the triple win (Staatsen et al, 2017).

Suggested Readings

Michie S, van Stralen MM, West R. (2011) The behaviour change wheel: a new method for characterising and designing behaviour change interventions. Implementation Science. 6.42. https://implementationscience.biomedcentral.com/articles/10.1186/1748-5908-6-42.

Rayner G, Lang T (2012). Ecological Public Health: Reshaping the Conditions for Good Health. Oxford: Routledge Publishers

Steffen W, Richardson K, Rockström J, Cornell SE, Fetzer I, Bennett E, Retrieved from et al (2015). Planetary boundaries: Guiding human development on a changing planet. Science. 349 No 6254 pp 1286-1287. Retrieved from https://science.sciencemag.org/content/347/6223/1259855.full United Nations (2015).

Transforming our world: the 2030 Agenda for Sustainable Development. Retrieved from https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf

Whitmee, S., Haines, A., Breyrer, C., Boltz, F., Capon, A.G., de Souza Dias, BF., et al. (2015) Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. Lancet 386(10007) 1973-2028. https://doi.org/10.1016/S0140-6736(15)60901-1

Rutter, H., Savona, N., Glonty, K., et. al., (2017) The need for complex systems models of evidence for public health. Lancet. Retrieved from https://www.repository.cam.ac.uk/bitstream/handle/1810/263581/1-s2.0-S0140673617312679-main.pdf?sequence=5&isAllowed=y

Acknowledgements

This research was funded in part with support from a) the European Commission Horizon 2020 funded INHERIT project, coordinated by EuroHealthNet [grant number 667364]; b) the Federal Ministry for Environment, Nature Conservation and Nuclear Safety of Germany; c) the General-Directorate of Health of the Ministry of Health of Portugal; d) the Portuguese National Institute of Health and the Faculty of Medicine of the University of Lisbon; e) the National Institute for Health Research Health Protection Research Unit (NIHR HPRU) in Environmental Change and Health at the London School of Hygiene and Tropical Medicine in partnership with Public Health England (PHE), and in collaboration with the University of Exeter, University College London, and the Met Office; and the UK Medical Research Council (MRC) and UK Natural Environment Research Council (NERC) for the MEDMI Project (https://www.data-mashup.org.uk).

The authors alone are responsible for the views expressed in this article and they do not necessarily represent the views, decisions or policies of the institutions with which they are

affiliated .nor those of the funders (none of whom were involved in the research design, data analysis or interpretation of findings and are not responsible for any use that may be made of the information contained within).

REFERENCES

Adger, W.N., Eakin, H., Winkels, A. (2009). Nested and teleconnected vulnerabilities to environmental change. Frontiers and Ecology and the Environment. 7(3):150–157. doi:10.1890/070148. Retrieved from https://ore.exeter.ac.uk/repository/bitstream/handle/10871/9254/adger.pdf?sequence=2

Baker, M. (2015). Over half of psychology studies fail reproducibility test. Largest replication study to date casts doubt on many published positive results. *Nature*. Retrieved from http://dx.doi.org/10.1038/nature.2015.18248

Berger, S.L., Kouzarides, T., Shiekhattar, R., et. al., (2009) An operational definition of epigenetics. *Genes and Development*. **23** (7): 781–83.

Casadevall, A., Fang, F.C. (2015) *Is science in crisis?*. Baltimore Sun http://www.baltimoresun.com/news/opinion/oped/bs-ed-science-crisis-20150725-story.html accessed 21 November 2017.

Crutzen, P.J. (2006) The "Anthropocene". In: Ehlers E., Krafft T. (eds) Earth System Science in the Anthropocene. Springer, Berlin, Heidelberg.

European Environment Agency (2013*) Late lessons from early warnings: science, precaution, innovation.* EEA Report No1/2013. ISSN 1725-9177, Copenhagen Eurpean Environment Agency.

Dahlgren, G., & Whitehead, M. (1991). *Policies and strategies to promote social equity in health.* Institute of Futures Studies. Department for Education and Skills, Stockholm.

Destoumieux-Garzón, D., Mavingui, P., Boetsch, G. (2018) One Health Concept: 10 Years Old and a Long Road Ahead. *Frontiers of Veterinary Science*, **12** Retieved from https://doi.org/10.3389/fvets.2018.00014

Dohler, M. (2012) *The role of science in regulation: scrutinising an uneasy relationship.* Paper for the 8th Transatlantic Dialog Johnston, J.S. (ed) (2012) Institutions and incentives in regulatory science. Plymouth: Lexington Books

Evans, R., & Stoddart, G. (1990). Producing health, consuming health care. *Social Science and Medicine*, 31, 1347-1363.

Feilden, T (2017) Many scientists can't replicate studies by their peers. BBC Science and Environment. Retrieved from https://www.bbc.co.uk/news/science-environment-39054778

Francesci, C., Campisi, J. (2014) Chronic inflammation (Inflammaging) and its potential contribution to age-associated diseases. *The Journals of Gerentology, Series A*, **69.** Issue Suppl. 1, pp S4-S9. Retrieved from Funtowicz, 2006

Funtowicz, S. (2006). Why knowledge assessment? In Guimarães Pereira, A.,. Guedes Vaz, S., Tognetti, S (Eds.), *Interfaces between science and society*, Sheffield: Greenleaf Publishing Ltd,

Funtowicz, S., Ravetz, J. (2018) Post normal science. In *Companion to Environmental Studies*. 443-447 (5) Routledge Publishers in association with GSE Research. Retrieved from https://www.ingentaconnect.com/content/rout/26bvfp/2018/00000001/00000001/art00086

Gell=Mann, M. (2010) Transformations of the Twent-First Century: Transitions to Greater Sustainability. In Global Sustainability: A Nobel Cause, ed Schellnhuber, H,J., Molina, M., Stern, N., HuberV., Kadner, S, Cambribge: Cambridge University Press.

Hill, A.B. (1965). The Environment and Disease: Association or Causation? *Proceedings of the Royal Society of Medicine*. **58** (5): 295–300. Retrieved from https://www.edwardtufte.com/tufte/hill

Ioannidis, J.P.A .(2014). How to make more published research true. PLoS Medicine. 11(10):e1001747. Retrieved from https://doi.org/10.1371/journal.pmed.1001747

Jasanoff, S. (1990). The fifth branch: science advisers to policymakers. Cambridge MA: Harvard University Press..

Johnston, J.S. (ed) (2012) Institutions and incentives in regulatory science. Plymouth: Lexington Books.

Kessel, A. (2006). *Air, the environment and public health*. Cambridge: Cambridge University Press

Landrigan, P,J. Fuller, R., Hu, H., et al, (2018) Pollution and Global Health – An Agenda for Prevention. *Environmental Health Perspectives*, **126**(8) 084501 1- 6, Retrieved from https://ehp.niehs.nih.gov/doi/pdf/10.1289/EHP3141

Lerner, H., Berg, C. (2015) The concept of One Health and some practical implications for research and education: what is One Health? *Infection Ecology & Epidemiology***. 5** (1) Retrieved from https://doi.org/10.3402/iee.v5.25300

Meinhardt, M. (2018) *A Longing for Wide and Unknown Things: The Life of Alexander Humboldt*. London: Hurst and Company

Michie S, van Stralen MM, West R. (2011) The behaviour change wheel: a new method for characterising and designing behaviour change interventions. Implementation Science. 6.42. https://implementationscience.biomedcentral.com/articles/10.1186/1748-5908-6-42.

Morey, R.D., Chambers, C.D., Etchells, P.J., et al (2016). The Peer Reviewers' Openness Initiative: incentivizing open research practices through peer review. Royal Society Open Science, 3(1): 150547. Retrieved from http://rsos.royalsocietypublishing.org/content/3/1/150547

Morris, G.P., Beck, S.A,, Hanlon, P., Robertson R (2006) Getting strategic about the environment and health. *Public Health* **120:**889–907

Morris, G., (2010) Ecological public health and climate change policy. *Perspectives in Public Health*..**130** No1 34-40

Morris, G., Reis, S., Beck, S., Fleming, L.E., et. Al. (2015). Climate change and health in the UK. Scoping and communicating the longer-term "distal" dimensions. In: Health Climate Change impacts report card technical paper No.10. Swindon, UK: Natural Environment

Research Council Retrieved from http://www.nerc.ac.uk/research/partnerships/ride/lwec/report-cards/health-source10/

Morris, G.P., Saunders, P. (2017) *The Environment in Health and Wellbeing*. OUP Encyclopaedia of environmental science. Retrieved from (http://environmentalscience.oxfordre.com/view/10.1093/acrefore/9780199389414.001.0001/acrefore-9780199389414-e-101?rskey=tGYyxX&result=8 accessed 21 January 2018

Morris, G.P., Reis, S., Beck, S.A., et. Al. (2017) Scoping the proximal and distal dimensions of climate change on health and wellbeing. *Environmental Health 16* Article No 116 https://ehjournal.biomedcentral.com/articles/10.1186/s12940-017-0329-y

NICE (2007) Behaviour Change: General Approaches. National Institute for Clinical Ecellence. Retrieved from https://www.nice.org.uk/guidance/ph6/resources/behaviour-change-general-approaches-pdf-55457515717

Open Science Collaboration (2015) Estimating the reproducibility of psychological science. *Science*, volume 349 (6251). Retrieved from https://curve.coventry.ac.uk/open/file/2cb6ae15-530f-49eb-9b32-87ea1ee9493c/1/Psychological%20science.pdf

Pearce W., Wesselink A., Colebatch, H. (2014) Evidence and meaning in policy making. *Evidence and Policy* 10(2): 161-165.

Petticrew M., Whitehead, M., Macintyre S., Graham H., Egan M. (2004) Evidence for public health policy on inequalities 1: The reality according to policymakers. *Journal of Epidemiology and Community Health*. **58:**11–816 Retrieved from http://jech.bmj.com/content/jech/58/10/811.full.pdf

Ravetz, J.R. (2016). How should we treat science's growing pains? The Guardian 8 June 2016.Retrieved from https://www.theguardian.com/science/political-science/2016/jun/08/how-should-we-treat-sciences-growing-pains

Rayner G, Lang T (2012). Ecological Public Health: Reshaping the Conditions for Good Health. Oxford: Routledge Publishers

Reis, S., Morris, G,, Fleming, L.E., et. Al. (2015). Integrating health and environmental impact analysis. Public Health. 129:1383–1389. Retrieved from https://www.sciencedirect.com/science/article/pii/S0033350613002424

Rittel H.W.J, Webber MM (1973) Dilemmas in a general theory of planning. *Policy Sciences 4* (2):155-169. Retrieved from https://archive.epa.gov/reg3esd1/data/web/pdf/rittel%2bwebber%2bdilemmas%2bgeneral_theory_of_planning.pdf

Rockström J, Steffen W, Noone K, Persson A, Chapin FS, Lambin E, et al (2009). Planetary Boundaries: Exploring the Safe Operating Space for Humanity. Ecology and Society. 14(2)32. Retrieved from http://www.stockholmresilience.org/download/18.8615c78125078c8d3380002197/ES-2009-3180.pdf

Royal College of Physicians (2016). *Every breath we take: The lifelong impact of air pollution*. Report of a working party. London: RCP.

Rutter, H., Savona, N., Glonty, K., et. al., (2017) The need for complex systems models of evidence for public health. Lancet. Retrieved from https://www.repository.cam.ac.uk/bitstream/handle/1810/263581/1-s2.0-S0140673617312679-main.pdf?sequence=5&isAllowed=y

Saltelli ,A., Funtowicz, S. (2017) What is science's crisis really about? *Futures*. **91:** 5-11. Retrieved from https://www.sciencedirect.com/science/article/pii/S0016328717301969

Saltelli, A, Giampietro, M. (2017) What is wrong with evidence based policy, and how can it be improved? *Futures* **91:** 62-71. Retrieved from https://www.sciencedirect.com/science/article/pii/S0016328717300472

Schroter, S., Black, N., Evans, S., et al. (2008) What errors do peer reviewers detect, and does training improve their ability to detect them? Journal of the Royal Society of Medicine. 101: 507–514.

Schutz, W. (2006) The cultural contradictions of managing change: using horizon scanning in an evidence-based policy context. *Foresight* **8**(4) 3-12

Scottish Government (2008) Good Places Better Health: A New Approach to Environment and Health in Scotland – Implementation Plan. http://www.gov.scot/Resource/Doc/254447/0075343.pdf

Scottish Government (2011) Good Places Better Health for Scotland's Children. Retrieved from http://www.gov.scot/Resource/0039/00398236.pdf

Staatsen, B., Van der Vliet, N.,. Kruise, H., at. Al. (2017) Exploring triple win solutions for living, moving and consuming that encourage behavioural change, protect the environment, promote health and health equity (INHERIT Background Report) Retrieved from https://inherit.eu/wp-content/uploads/2017/06/INHERIT-Report-A4-Low-res_s.pdf

Steffen W, Richardson K, Rockström J, Cornell SE, Fetzer I, Bennett E, Retrieved from et al (2015). Planetary boundaries: Guiding human development on a changing planet. Science. 349 No 6254 pp 1286-1287. Retrieved from https://science.sciencemag.org/content/347/6223/1259855.full

Stern, N. (2016) Building on Success and Learning from Experience An Independent Review of the Research Excellence Framework. An independent review commissioned by the UK Minister for Universities and Science. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/541338/ind-16-9-ref-stern-review.pdf

Strassheim, H., Kettunen, P. (2014) When does evidence-based policy turn into policy-based evidence? Configurations, contexts and mechanisms. *Evidence and Policy* **10**(2): 259-77.

Susser, M., Susser, E. (1996) Choosing a future for epidemiology : Eras and Paradigms. *American Journal of Public Health* **86:** 668-673. Retrieved from http://ajph.aphapublications.org/doi/pdf/10.2105/AJPH.86.5.668

United Nations (2015). Transforming our world: the 2030 Agenda for Sustainable Development. Retrieved from https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf

United Nations (2016) The New Urban Agenda – Habitat III Retrieved from http://habitat3.org/wp-content/uploads/NUA-English.pdf

Van Rij, V. (2010) Joint horizon scanning: identifying common strategic choices for knowledge. *Science and Public Policy* **37**(1)

Van der Vliet, N., Staatsen, B., Kruize, H., et. al. (2018) INHERIT model: a tool to jointly improve health, environmental sustainability and health equity through behavior and lifestyle change. *Int. J. Environ. Res. Public Health* **2018**, *15*(7), 1435;. Retrieved from https://www.mdpi.com/1660-4601/15/7/1435/pdf

Vineis, P. (2017). *Health without borders*. Cham, Switzerland: Springer

Weed, D.L. (1998). Beyond Black box epidemiology. *American Journal of Public Health* **88**(1) 12-14.

Whitmee, S., Haines, A., Breyrer, C., Boltz, F., Capon, A.G., de Souza Dias, BF., et al. (2015) Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. Lancet 386(10007) 1973-2028. https://doi.org/10.1016/S0140-6736(15)60901-1

WHO (2012a) Health 2020: a European policy framework supporting action across government and society for health and wellbeing Retrieved from http://www.euro.who.int/__data/assets/pdf_file/0006/199536/Health2020-Short.pdf.

WHO (2012b) Environmental health Inequalities in the European Region. Retrieved from http://www.euro.who.int/__data/assets/pdf_file/0010/157969/e96194.pdf

WHO (2017a) Environmental health in Europe: Status and Perspectives http://www.euro.who.int/en/health-topics/environment-and-health/pages/european-environment-and-health-process-ehp/environment-and-health-in-europe-status-and-perspectives

WHO (2017b) *Setting research priorities in environment and health*. Report of a meeting held in Cascais, Portugal, April 2017 Retrieved from http://www.euro.who.int/en/health-topics/environment-and-health/Climate-change/publications/2017/setting-research-priorities-in-environment-and-health.-report-of-a-m. eeting-2017

WHO (2019a) *Setting research priorities in environment and health.* Report of a meeting held in Bonn, Germany 30 November-1 December 2017 Retrieved from http://www.euro.who.int/__data/assets/pdf_file/0007/394198/rp-eh-eng.pdf?ua=1

WHO (2019b) Environmental health inequalities in Europe. Second assessment report. Retrieved from http://www.euro.who.int/en/health-topics/environment-and-health/air-

quality/publications/2019/environmental-health-inequalities-in-europe.-second-assessment-report-2019

WHO (2018) *Circular economy and health: opportunities and risks.* http://www.euro.who.int/__data/assets/pdf_file/0004/374917/Circular-Economy_EN_WHO_web_august-2018.pdf?ua=1

Wild, CP (Aug 2005). "Complementing the genome with an "exposome": the outstanding challenge of environmental exposure measurement in molecular epidemiology". *Cancer Epidemiology, Biomarkers & Prevention*. **14** (8): 1847–50. doi:10.1158/1055-9965.EPI-05-0456

Wilsdon, J. 2014. Evidence-based Union? A new alliance for science advice in Europe. In The Guardian.: Retrieved from https://www.theguardian.com/science/political-science/2014/jun/23/evidence-based-union-a-new-alliance-for-science-advice-in-europe

Wilsdon J. (2015). We need a measured approach to metrics. Nature, 523: 129. Retrieved from http://www.nature.com/polopoly_fs/1.17928!/menu/main/topColumns/topLeftColumn/pdf/523129a.pdf