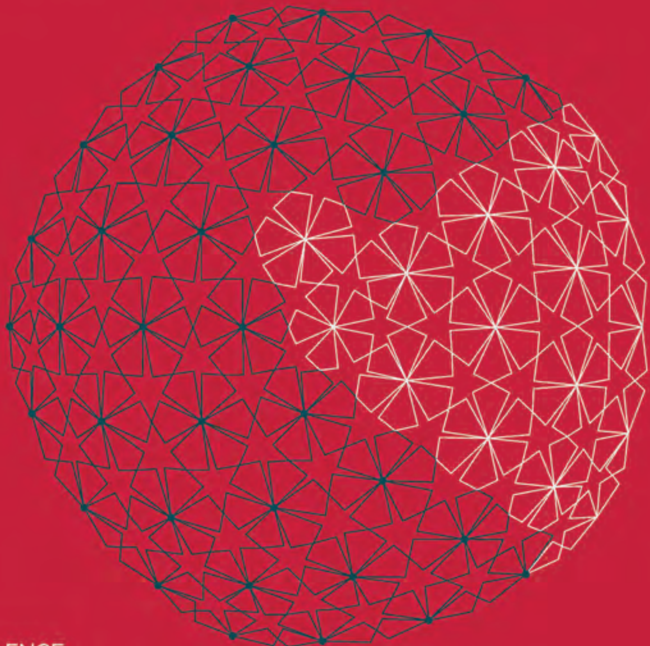
Geoengineering the climate

Science, governance and uncertainty

September 2009



EXCELLENCE IN SCIENCE

THE ROYAL SOCIETY

SCIENCE, POLICY & CONTROVERSY IN FISHERIES MANAGEMENT, NUCLEAR WASTE AND CLIMATE CHANGE

foredrag på fellesmøte
den 8. september 2011

av professor John Shepherd, School of Ocean & Earth Science, National Oceanography Centre, University of Southampton, UK

Kommentarinnlegg ved Tor Saglie og Lars Walløe fra Universitetet i Oslo

Summary

Controversy often arises over the scientific basis for public policy, with a conflict between scientific rigour, socio-economic objectives and political expediency, which can become severe. Experience in several fields (Fisheries Management, Pollution Control and Climate Change) suggests that this is usually due to fear, uncertainty and doubt, which may arise naturally but can also be magnified by interest groups to promote their views. This can be reduced by good communication and transparency, and by greater independence and independent peer review of the scientific advice. However controversy is inevitable unless mutual trust can be achieved, and even these ingredients may not be sufficient if policies involve an uneven distribution of risks and benefits.

1. Introduction

Scientific advice is nowadays an essential ingredient of public policy on a number of issues of great importance to society. There can often be controversy over the basis of the scientific advice, arising from a conflict between scientific rigour, socio-economic objectives and political expediency, which can become severe. My credentials for having an opinion on these subjects are a first degree and PhD in physics, then successively mutating into an applied mathematician, a fisheries scientist, an oceanographer, and finally an earth system & climate modeller. I have had experience working for industry on air pollution (the fate of SO_2), for government on the control of radioactive waste disposal and fisheries management, as an independent consultant on marine pollution (especially the decommissioning of offshore oil installations, and for a university on oceanography and climate change. Most recently I have chaired a major review, for the UK's Royal Society, on geoengineering: a very controversial subject indeed.[1] My experience in these several fields (especially on fisheries management, control of radioactive waste disposal, climate change and geoengineering) leads me to propose that controversy is usually due to fear, uncertainty, and doubt (FUD) about the scientific evidence and the socioeconomic consequences of policy. FUD may of course arise naturally, but it can also be deliberately magnified by interest groups in order to promote their own views. The problems are often made worse by lack of general understanding even of very basic science, poor communication of risks, deliberate propagation of misinformation, and lack of trust. I review the nature of FUD in each of these fields, and their sources, and make some suggestions on how they may be reduced. The possible "solutions" include better communication and transparency of scientific results, more independence of scientists, greater freedom to publish and independent review of the scientific evidence. However, it is human nature to dismiss the basis for actions which may affect us adversely, and it is inevitable that the scientific evidence will be attacked if its consequences are unwelcome, and this is not a problem that can easily be fixed.

2. Fear, Uncertainty & Doubt, and Socioeconomic Issues

According to Wikipedia, "FUD is a tactic used in sales, marketing, public relations, politics and propaganda. It is generally a strategic attempt to influence public perception by disseminating negative and dubious or false information, designed to undermine the credibility of their beliefs". This tactic has been widely used, and is widely recognized as being highly effective. However, FUD may not be just a tactic deployed by the devious: it may arise naturally, and only need to be nurtured …

1. Royal Society (2009) "Geoengineering the Climate: Science, Governance and Uncertainty", Policy document, 10/2009, London, 98pp.

We all understandably fear something bad happening, to us, to our family and friends, to people generally, to the economy, or to the environment. And many policies pursued by the powerful, whether they are underpinned by science or not, have the capacity to do just that. Such fear is not necessarily unreasonable at all, and it can be a powerful survival mechanism, nurtured by evolution. However, it does matter whether the basis for the fear is sound or not. Fear can paralyse as well as galvanise, and if unfounded is unlikely to help us make good decisions. The task of the scientific adviser and the policy-maker is therefore to try to ensure that the level of fear is reasonable, and proportionate to the real risks, rather than imagined ones.

Uncertainty is also a fact of life, and we all have ways to deal with everyday risks. Will it rain today? Shall I take my umbrella? However, it becomes more difficult when the uncertainty concerns life-changing risks, and these arise from matters of which we know little, which for most people sadly means anything scientific. Moreover, uncertainty comes in various flavours[2]: these include imprecision, irregularity, and ignorance. **Imprecision** merely involves some uncertainty about a well-understood factor (i.e. possible errors in some parameters, estimates or observations, due to **measurement errors/noise**). An everyday example would be: will that new car really have the fuel consumption that the makers claim? **Irregularity** (or **process error/noise**) often occurs when the process at work is itself not fully predictable (i.e. it is stochastic). As an example: I cannot know whether the gearbox of my car will fail this year or not: I can only assess the probability of that. Or, I cannot predict the weather very accurately, because the atmosphere is turbulent. **Ignorance** also comes in several flavours. It may involve a simple error (they do happen). For example, I thought that the car would be reliable, but it had a lot of faults. This is closely related to a lack of knowledge or an error about the processes involved (**model error or mis-specification**): for example, the calculations assumed that wind resistance increased as the square of the speed, but it should really have been a cubic relationship (say). Finally of course there is complete ignorance: the

2. Stirling, A. (2003) “Risk, uncertainty and precaution: some instrumental implications from the social sciences” in “Negotiating environmental change: new perspectives from social science” edited by Frans Berkhout, Melissa Leach & Ian Scoones, Edward Elgar Publishing, Cheltenham, UK.

"unknown unknowns" made famous by Donald Rumsfeld.[3] We can't allow for the effects of things if we don't know that they exist (the health damage from X-rays when they were first discovered, for example). All of these forms of uncertainty are likely to exist in any scientific assessment, and if they are sufficiently large they will help to undermine its credibility. The problems are of course magnified if we are uncertain about the magnitude of the uncertainty, and this is inevitable in the case of the unknown unknowns.

All of these forms of uncertainty will naturally lead on to our second ingredient, doubt. As those simple examples show, doubt is a normal and useful state of mind, and we live with it every day. Similarly scepticism is a natural and rational state of mind. Indeed, science itself can properly be described as "organised scepticism".[4] However, extreme doubt can easily lead to disbelief, and so lead on, through dissent, to denial…

Doubt => Disbelief => Dissent => Denial

All of these states of mind are proper and rational in the appropriate circumstances: one can easily imagine jurors in a court of law exhibiting all of them. Which is the most appropriate depends of course on the **strength of the evidence**. It is rational to believe something if there is strong evidence for it, and to disbelieve it if the evidence is against it. Indeed, that is almost a definition of rationality, and it is what a juror is expected to do: to do otherwise is irrational (and unacceptable). Most so-called "climate-change sceptics" are in fact not just sceptical, but dissenters, and this term is apt and useful since "deniers" tend to be regarded as pejorative. The problem for science-based public policy arises when these states of mind are held inappropriately. But who is to judge what is the appropriate level of doubt or belief?

That question leads us to the socio-economic dimension of this issue (and most others) on which I am far from expert. There are cultural, moral

3. The phrase was used by Rumsfeld in 2002 in connection with the presence (or absence) of weapons of mass destruction in Iraq, but was apparently used much earlier by others, including a thirteenth-century Tajik poet called Ibn Yamin (according to Wikipedia!).
4. May, R.M. (2010), "Science as organized skepticism", Phil. Trans. R. Soc. A, 369 (1956) 4685-4689 December 13, 2011; doi:10.1098/rsta.2011.0177 (an opinion piece for the Royal Society meeting on Handling Uncertainty in Science, http://royalsociety.org/events/2010/uncertainty-science/)

and ethical aspects of policy formation (see for example Eden 1996)[5] which can over-ride simple-minded "rational" arguments. However, at a more prosaic level, people tend to react to policies according to how they will affect them (and their family and friends, or more generally their "tribe"). This is not just about money, although the fiscal and economic aspects of any policy are almost always relevant. Effects on people's lifestyles is also a powerful factor: for example, any policy which is likely to curtail one's ability to fly away to the sun, or drive the car of one's choice, can be guaranteed to receive close (and skeptical) scrutiny. Indeed, new policy is always about change, and almost all change is likely to create winners and losers; moreover, these may be in different places (different countries, perhaps) and live at different times. Almost all of us accept that we should take some account of the likely impacts of policy on future generations, but the details of this (how much weight should they be given, and how should it be done?) are guaranteed to stimulate debate. Aggregating over those winners and losers is also not straightforward. To follow Bentham and aim simply for the "greatest good of the greatest number" [6], the basis of the utilitarian approach to ethics, appears plausible at first sight but is easily shown not to be a universally applicable approach.[7] Alternative approaches such as a Rawlsian maxi-min approach exist (see Stigliz et al 2009)[8], but none is universally accepted, and all involve more or less arbitrary assumptions and invidious choices. Even if we were all agreed that some such overall welfare objective should be pursued (which is unlikely given the prevalence of so-called libertarian opinions), many people are likely to lose in one way and to win in another (or perhaps at another time). And it is virtually certain that anyone who perceives themselves (or their tribe) to be overall losers, would subsequently object to and oppose whatever has been proposed, even if some such calculation showed that it would be of general benefit.

Thus we can see how uncertainty in the assessment of the impacts of any proposed innovation can lead naturally to doubt about its desirability, and

5. Eden, S. (1996) "Public participation in environmental policy: considering scientific, counter-scientific and non-scientific contributions", *Public Understanding of Science*, 5, 183–204.
6. Bentham, Jeremy (1776). *A Fragment on Government*. London, Preface (2nd para.).
7. see for example the amusing moral puzzles involving lifeboats, trains and people thrown from bridges at http://www.friesian.com/valley/dilemmas.htm
8. Stiglitz J.E., A. Sen, J.P. Fitoussi (2009), Report by the commission on the measurement of economic performance and social progress, https://new.cbd.int/doc/case-studies/inc/cs-inc-report.commission-en.pdf

fear about its consequences. Some level of FUD is inevitable, and it is its interaction with socio-economic consequences that leads to the **extent of public concern** about a particular issue. I shall discuss how the various factors interact in a few cases of which I have some personal experience below. All of this should sound familiar. An early investigation by the Royal Society, more than 200 years ago, was into the efficacy and utility of lightning conductors[9], a matter of great uncertainty at the time. Establishing and communicating scientific advice on matters which are uncertain is hardly new. Whether it is helpful to embellish it by calling it by the obscure term "post-normal science"[10], which is quite meaningless to most people, is doubtful. I remain skeptical!

3. Case studies: Fisheries, Nuclear Waste and Climate Change

3.1 Fisheries Management

Fisheries assessment is not an exact science, but when proper data are available, the quality of the science is often good enough for us to know roughly what should be done, at least in the short-term (say with uncertainties of 50% or less). The problems are usually that we have only inadequate (or no) data, because it has been corrupted by misreporting and illegal landings, or that the management system (like TACs and quotas) makes unreasonable demands on what science can deliver. Long-term management is harder because of the very high uncertainty of any prediction of future recruitment of young fish (and specifically of the stock-recruitment relationship): this is an excellent example of process error/noise (q.v.). Even then the *sign* of any changes to management that are needed may be clear, although the magnitude may be uncertain. The problems (and causes of controversy) of fisheries management are usually mainly ***economic***, because the only way to conserve fish is to catch fewer of them, which invariably means lower landings and earnings, at least in the short-term. All effective conservation measures are therefore likely to hurt: and no-one is likely to accept a substantial reduction in their earnings without complaint (even if their operational costs are also reduced, which they may be). This means that we have a time-shift problem:

9. Scaffer S (2010) "Charged Atmospheres", pp 132–155 in Bryson B. (ed) "Seeing Further", Harper Press, London, UK.
10. Funtowicz S.O. & Ravetz J.R. (1993) "Science for the post-normal age" Futures, Vol 25, (7), 739–755.

essentially a conflict between short-term losses and (potential) long-term gains, which is exacerbated by the considerable uncertainty in the latter. In this case however the same people are both the winners and the losers, which should simplify matters, except that those concerned tend to discount their likely future gains rather heavily.[11] In addition, the likelihood of ***lifestyle change*** is also an issue here: fundamentally most fishermen like to fish. They generally do not want to change to another way of living, and regard change (especially if imposed by outsiders, including the government) as a threat. In this case therefore, uncertainty in the science exacerbates the controversy, but is not the primary cause of it. Fisheries management would still be controversial even if we could predict the future precisely.

3.2 Nuclear Waste Disposal

Most people (even among scientists) hardly understand the risks of radiation at all: if one asks people whether they would be happy to receive a whole-body dose of 5 Gray, the dominant response is invariably "don't know".[12] Similarly most people have no conception of the different properties of alpha, beta or gamma radiation, let alone of neutrons. They generally assume that exposure to any form of radiation causes contamination, but have no idea what to do if they should become contaminated.[13] It is therefore an invisible & intangible hazard that is not understood, and of course it is associated with the horrors of nuclear weapons. Fear and ignorance are here the dominant causes of controversy. Fear of the unknown is a fair and reasonable position, and is probably selected for by evolution. However, where (as here) much appropriate knowledge is readily available, surely we could avoid the paralysing levels of controversy caused by these uncomprehended risks, through more and better education? Then it might be possible to have a more measured debate on the risks of dealing with radioactive waste, and on the balance of the advantages and disadvantages of using nuclear power? Personally, I regard dealing with nuclear waste as a less difficult problem than that of dealing with climate change, because on the global scale the risks are relatively well understood and probably not so difficult to avert or mitigate.

11. See e.g. Hannesson, R. (1987) "The effect of the discount rate on the optimal exploitation of renewable resources, Norwegian School of Economics and Business Administration, Institute of Fisheries Economics (11pp).
12. In fact this is roughly the LD50 for an acute exposure (i.e. likely to be a lethal dose) so the answer should be an emphatic "No".
13. Washing with soap and water would generally be a good start.

3.3 Climate Change

Climate change is an interesting case, because despite all the media hype, and the doubts peddled by dissenters, the uncertainties in the science are not all that great, at least on the centennial timescale. The climate sensitivity is very likely known to within a factor of about 1.5 either way, which is quite sufficient to give the sign and the approximate magnitude of changes to be expected. There is however much greater uncertainty over future emissions, which are not predictable by scientific methods because they depend almost entirely on human behavior. These uncertainties are therefore primarily socioeconomic, although there are of course practical & technical uncertainties as to which technologies we should use and how fast we should deploy them. The economic consequences (the costs of mitigation and adaptation to deal with climate change) are only moderately large (a small percentage of GDP[14]) so it does not matter much if they too are uncertain. Their impacts are of course likely to be ***inequitable*** (the biggest losers are likely to be the most vulnerable people and countries) although this does not yet figure in the debate as much as it should. The big factors at work seem to be fear (in the developed world) of the changes of lifestyle that may be needed, as well as the laughable theory that it is all a conspiracy manufactured by left-leaning scientists in order to promote world government (which by assumption would be a Bad Thing, for some reason). Thus even though most informed commentators are convinced that anthropogenic climate change is "beyond reasonable doubt", the level of public doubt remains high, because the doubt has been largely deliberately manufactured[15]. Curiously, in most quarters the level of fear about the future physical consequences of climate change is quite ***small*** (and I would argue, unrealistically so). It is fear of the socio-economic consequences of doing anything about it that seems to dominate.

Before leaving climate change I should mention the topic of geoengineering, or deliberate intervention in the climate system in order to moderate global warming. There are two main methods proposed by which this might be done,[15] carbon dioxide removal (CDR) and solar radiation management (SRM). No-one knows yet whether this is really feasible, let alone desirable. The levels of fear, uncertainty and doubt are all very high, and rightly so. It may indeed be hubris even to contemplate such technology,

14. Stern, N. (2006) *The Economics of Climate Change*, Cambridge University Press, UK
15. Conway, E.M. & Oreskes, N. (2010) *Merchants of Doubt*, Bloomsbury Publishing, London, UK.

when there are very high levels of uncertainty about almost everything (feasibility, costs, effects, environmental impacts, unintended and unforeseen consequences …). Socioeconomic concerns also loom large here, especially about the possible equity issues. Indeed these are more prominent than they are for climate change *per se,* even though the intention is to ***reduce*** the (inequitable) impacts of climate change, especially for those who are the most vulnerable. It seems that we are more concerned about the inequitable consequences of deliberate actions than we are about those of accidental actions (though many would argue that continuing to cause climate change is no longer accidental). There are also major concerns about our ability to govern geoengineering adequately, and the Royal Society is co-sponsoring the Solar Radiation Management Governance Initiative[16] to explore these issues in relation to some of the trickiest problems.

4. What can we do to reduce FUD and controversy?

Nobody minds controversy so long as it is well-informed and well-argued: indeed, it is to be welcomed as part of the process of reaching decisions. However, excessive and unnecessary controversy can paralyse the process. I discuss here some things that may be useful to help adjust the temperature of debate to a constructive level. They fall into several broad areas, including

- Education (teaching and learning) and Research
- Communication (talking and listening, dialogue & debate)
- Establishing Trust (through openness & transparency)
- Ensuring Independence & Publication (including independent peer review)

4.1 Education

In general, we can and should try to make the debate better informed, by increasing knowledge and understanding. The term "Public Understanding of Science" is now unfashionable, because we should (of course) engage in an exchange of views, and not just lecture people. However, it is almost impossible to have such an exchange on any novel subject unless all concerned share some common understanding of the subject. So education is often

16. For more information, see www.srmgi.org

necessary, and that involves both teaching and learning, by both "us" and "them". Education requires the preparation of good teaching material, that responds to the students questions and needs. But it also requires the motivation to learn, and to devote some non-trivial effort to the process, including (for example) things like self-study & attending courses, and maybe even buying and reading books. People also need access to trusted sources, to avoid the propagation of misinformation (of which I shall say more below). Posting questions on a blog and expecting free tutorials is unlikely to be enough, despite the current trend towards such expectations of instant enlightenment.

4.2 Research

As we have seen, uncertainty exacerbates controversy, creating fertile ground for disagreement. It can almost never be eliminated, but it can be reduced by acquiring new knowledge, and humankind has invented a wonderfully effective process for doing that: scientific research (in the broadest sense). Research comes in various flavours, usually categorized as basic, strategic and applied. Of these basic research is by definition far from practical application and so usually not too controversial. Applied research is likely to be so-called "normal science", and it is strategic research that usually creates most concern, because it is both less certain yet likely to be of practical value. Research is carried out in various places, including universities, industry, and government laboratories (and sometimes even by individuals working alone). The location is not unimportant: it may create perceptions of conflicts of interest, and so compromise trust in the researchers and their results (see below). Publication of the results is necessary for them to have value: and this should be as open, wide and complete as possible, not only to promote communication, but also because the right to open publication is the best guarantee of independence from the paymasters. The problems of restricted access to the literature have always been present with the old system of paid subscriptions to journals. However, they have been brought to a head now that there are so many interested non-professionals trying to access papers that they have heard about through the internet. Academics are insulated from this because they have superb access via their university libraries and subscriptions to e-journals. It is only necessary to work for a short while from somewhere that lacks such access (i.e. almost anywhere outside academia, and especially in the developing world) to realize what a disadvantage this creates. We need to develop and promote universal open and free-to-access business models for scientific publishing as fast as we possibly can. Otherwise we can be justly criticized for perpetuating a priest-hood.

4.3 Communication

Good communication of science is hard. It needs both talent and expertise, including the ability to allow for any lack of knowledge and possible misunderstanding by the listener. That is why a two-way process (in a classroom, say, or a pub) is the best: one has to listen, and thereby appreciate any possible mis-conceptions before they can be addressed. With the published and broadcast media, the problems are much more severe, because there is little or no chance for interaction: no opportunity for those "Ah, I see what you mean" moments. There are other problems, especially if the subject matter is controversial, even if it is purely factual. There is accumulating evidence that we are much more likely to trust and accept what is said by "people like us".[17] This is essentially tribal behaviour, which is probably pervasive because it has survival value. Many scientific disciplines are however still largely populated by old white males (mostly from the Northern hemisphere). We need more trustworthy and diverse communicators, and that means that we need more diversity in science. However, there is a conflict here, because the results of research with focus groups[18] show that people are also much more likely to accept new (and possibly unwelcome) information from trusted and well-known personalities to whom they can already relate. Such people are in short supply: almost certainly we must keep on trying to use all of the channels of communication that we can: there is no magic bullet.

Another problem (for scientists) is that the media are so ephemeral and demand short and simple messages (especially TV & radio). Scientists are used to publishing once (and only once): re-publishing the same material is unprofessional, and very much frowned upon. We find it quite distressing to spend many hours contributing to a TV programme (say), only to have another company or channel come along a few months later, wanting to do it all over again (especially since repeat showings of science programmes are so rare). And news programming is even worse, with the traditional half-life of about nine days (at best). Can this be overcome? Probably not. Web archives of TV and radio programmes are just getting to be useful, but until

17. "Communal reinforcement": see e.g. Goldacre, B. (2008) *Bad Science*, Fourth Estate, London, UK, chapter 13.
18. Emily Shuckburgh (British Antarctic Survey, Cambridge) *pers. comm.*

they are more easily searchable, they will not make a big difference. For the printed and broadcast media we probably have to accept that "Eternal repetition is the price of comprehension".[19]

More serious is the "pernicious balance" problem[20], i.e. the tendency to give equal air-time to opposing views on every scientific issue that is in any way controversial, irrespective of the balance of informed opinion on the matter. This could be easily solved: a clear and authoritative ruling that an obligation to be "fair and balanced" in covering such matters means giving coverage roughly in proportion to the prevalence of the opinion would suffice.[21] This is familiar territory: in the UK we require it for political broadcasts during an election. We do not give equal air-time to the Monster Raving Loony Party[22], and rightly (though perhaps sadly) so. We need some similar system for science.

Finally, we need to recognise that every caveat and qualification makes the message harder to understand, whether one is speaking to the public directly, to policy-makers or to the media. Two or three simple, clear and unambiguous statements should be the goal. That is usually very hard to achieve, but judicious use of carefully chosen qualifying words (rather than convoluted phrases or extra sentences) can help. We could do better, and should try harder!

4.4 Socioeconomics

We have seen that socioeconomic issues are invariably very important. People tend to have an intuitive reaction: they either like or dislike certain courses of action: and if you don't like a proposed course of action, for any reason, a common and very effective technique is to attack the evidence that supports it … There can be many reasons for such preferences, so there can be no simple solution. But there are some things that may help. Some-

19. A revised version of a misattributed quotation, since apparently Thomas Jefferson never said "Eternal vigilance is the price of freedom", though John Philpot Curran did say "The condition upon which God hath given liberty to man is eternal vigilance": see http://en.wikiquote.org/wiki/Thomas_Jefferson
20. This phrase was (probably) first used in 1814 by John Adams, commenting on the constitution of the USA. Recent events have shown him to be prescient. For the original context see http://federalexpression.wordpress.com/2011/02/02/the-seventeenth-amendment-the-great-compromise-undone/
21. See also Steve Jones's report for the BBC on the impartiality and accuracy of its science coverage at http://www.bbc.co.uk/bbctrust/assets/files/pdf/our_work/science_impartiality/science_impartiality.pdf
22. Yes, it really does exist: see http://www.omrlp.com/

times people object because many (maybe most) courses of action create losers. It is common to object if one expects to be among the losers, and not uncommon to object simply because the consequences will be inequitable (i.e. on behalf of the losers, whoever they may be). A good start here is to admit that there is a problem, and try to estimate its extent. The purpose of this is not to eliminate the problem, which may be impossible, but to try to establish the context and scale of it, in order to establish a sense of proportion. If there are going to be losers, it may help to admit this, and try to find practical ways to deal with liability for the losses. There are many situations where it is better to avoid enriching lawyers by insisting on legal process and proof: mechanisms that accept collective responsibility, and allow for appropriate automatic compensation can be much more practical, and cheaper, even if they involve rather rough justice. Another helpful process is to recognize and accommodate, and wherever possible to seriously address alternative views. The word "respect" is often used here, but that can be difficult, and to ask too much: toleration should be enough. Next, many people (and perhaps especially scientists) tend to seek the best possible solution to a problem. That may also be too much: an ***optimal*** solution may not even exist, or may be too hard to reach: an ***adequate*** one may suffice. It often helps to accept some level of imperfection (and I think that engineers are much better at this than scientists).

4.5 Risk: Perception & Confusion

One factor that understandably increases FUD is the perception that some proposed course of action involves risk, not least because risks are inherently uncertain. The word "risk" is one that everyone uses and understands in a general way, but which is used with a specific meaning by specialists. To them, a risk is not the same as a hazard (a possible event that may cause harm), since it is defined as the probability of a hazard multiplied by its consequence.[23] All this is very confusing. In particular there are no clear standards for measuring and communicating risks: they are often expressed in terms of other (supposedly more familiar) risks, such as those of smoking cigarettes or crossing the road. It would, I think, be useful if there were a standard unit. This needs to be appreciable, and should be fairly large, so

23. It is not obvious that all such risks are perceived equally: many people are more concerned by risks that are involuntary, or catastrophic, so some form of weighting may be needed.

that the scale is naturally comprehensible.[24] I propose that we should choose a unit corresponding to one likely death, and call it a "mort"[25] (say). Then the inescapable background risk of being alive at all is about 0.01 morts per year, 1 megamort is a catastrophe, and 1 micromort is probably negligible for an individual. This is far from a solution to the many problems of understanding risk, but might help people to maintain a sense of proportion.

4.6 Dealing with Misinformation

Peer reviewed publications are the life-blood of science, and peer review is of course science's imperfect system of quality assurance … like democracy, it is so far the least bad system invented, and a lot better than nothing. Its merits are most obvious when it is absent, for example on the internet where false and misleading information proliferates. We really need some sort of quality ratings for information on the internet, and I am delighted that Wikipedia has begun to address this problem with its new ***Article Feedback Tool***. [26] This is a good start, but it will take time for such a system to be deployed generally (and those posting lies are unlikely to make it available). Another problem is that there is in effect no cost threshold for posting or accessing information, but there would surely be major opposition to having any sort of "pay to post" system (like a Tobin transaction tax). A more radical suggestion is that we should make it a ***criminal offence*** to publish false or misleading information (anywhere, not only on the internet). This could perhaps replace our existing (and deeply unsatisfactory) civil libel laws. Like speed limits, it could only be enforced by occasional exemplary prosecutions (perhaps mainly by NGOs), but could help to solve other problems having nothing to do with science.

4.7 Who should we trust? Independent Review

A related problem is that, outside our own fields of expertise, all of us have difficulty deciding whom we should trust, when conflicting opinions are presented. However, this is a common problem in everyday life too. How do we set about choosing a surgeon, a plumber or a car mechanic? The com-

24. For example most people would be likely to think that a mega-becquerel is far more than a micro-curie, but they would be wrong (it's only about 30 times more).
25. Such a unit is in fact used in Health & Safety studies, which estimate and compare PLL values: denoting probable loss of lives.
26. This is not yet available on all pages, but is accessed via the "Rate this page" and "View ratings" buttons at the bottom of the page.

mon criteria we use include having appropriate qualifications, relevant experience, a good track record (i.e. for scientists, recognized publications), and preferably personal recommendations. Most of these can be used to judge the quality of sources of scientific information too. There are of course also other and less tangible factors involved. These include openness & transparency. As the UEA "Climategate" email episode demonstrated, any hint of lack of openness can be very damaging. More generally, having the ability and willingness to publish is a vital ingredient of the scientific process. For this reason (as well as the perception of influence by vested interests) scientists working for government and industry are not trusted as much as academics, even though they can and do much good work. In the UK almost all government departments now have senior academics who serve as Chief Scientific Advisers to ensure the quality of in-house work, and Science Advisory Committees to prevent them "going native". In addition many major (and potentially controversial) scientific/technical projects now establish Independent Review Groups to ensure that the evidence used is sound. Since the Brent Spar affair this has become common for major offshore decommissioning projects (though curiously not for exploration and production). All these people are normally paid, as consultants or professional advisers: how can they claim to maintain their independence? In my experience, ***freedom to publish*** their findings (without prior approval) is the crucial guarantee, and I would not undertake such work without it. In my opinion independent review is almost always useful, especially of commissioned research where the danger of the paymaster calling the tune is greatest.

5. Conclusions

If the science being done is important and useful to the public, it's quite likely to be controversial, and those concerned should not complain if they need to take socioeconomic issues into account. And, because the tactic of attacking the scientific basis if you don't like the answer is so effective, they should expect to have to demonstrate that their evidence is sound. Here they are at a disadvantage, compared to (say) politicians, journalists, and bankers, for two reasons. Firstly scientists have an exaggerated respect for the truth, because it is (we trust) their life's work to find it. Second, they admit to uncertainty: most others don't (even when the evidence for their views is minimal). As Benjamin Franklin said (in 1789) "Nothing is certain except death and taxes", but few other professions care to admit it. Moreover, theories can rarely be proven, usually they can only be disproven.[27] This is deeply counter-intuitive, and both of these issues contribute to the "unnatural" nature of science.[28] Very little in practical science can therefore be seen in black and white terms: it is all in shades of grey. The best we can usually do is to attach confidence levels to statements, and sometimes even that is difficult. Can we reduce that problem? Perhaps. We can try to use more positive, and clearer language. We could (when appropriate) say "virtually certain" as well as very likely or probable. We could say "beyond reasonable doubt" for things that have 95 % confidence. And we could use the language of odds, and say that it's "ten to one on" that climate change has been caused by humans. Finally, we must be prepared to repeat ourselves, over and over again, accepting that "Eternal repetition is the price of comprehension".

Professor John Shepherd chaired in 2009 a major review for the UK's Royal Society on geoengineering, "Geoengineering the Climate: Science, Governance and Uncertainty".

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The complete report can be downloaded from:
http://royalsociety.org/policy/publications/2009/geoengineering-climate/

27. When things can be proved, in mathematics and in science, it is usually only by disproving the only alternatives.
28. Wolpert, L. (2000) *The Unnatural Nature of Science* Faber & Faber, London, UK.