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Balancing the Risks: Choosing Climate Alternatives

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Abstract. Very aggressive reductions in greenhouse gas emissions are needed over the next ten years to avoid a "planet on fire." Current sub-national, national and international policy assumes that carbon sequestration, biofuels, nuclear power, ocean fertilization, atmospheric aerosols, and other such technologies, which heretofore have been considered too novel or too dangerous to use, will have to be deployed at large scale, globally. Moving forward with promising technologies that might preserve us from the consequences of global warming will be difficult because they also pose potential hazards, promise uncertain benefits, and in some cases are already burdened with restrictive legislation and poor public image. The lack of a rational process of risk assessment and public decision making is likely to lead to a poor long-term outcome. Moreover, the standard administrative and political processes used to assess such risks can take years, time that we do not have. Principled and practical policymaking demand citizens participate in the decision to develop and use these novel technologies. Environmental assessment, horizon scanning, and new research on human and organizational factors suggest techniques to improve technology development decisions.

1. Defining the problem

"All scientific work is liable to be upset or modified by advancing knowledge. That does not confer upon us a freedom to ignore the knowledge we already have, or to postpone the action that it appears to demand at a given time" [1].

Very aggressive reductions in greenhouse gas emissions are needed over the next ten years to avoid a "planet on fire." A great challenge for policymakers today is to introduce low carbon technologies on a fast-track without sacrificing environmental and human health or equity. Democratic, environmental and human rights principles require processes that weigh a range of values and expert opinion.

It is now believed that global average temperature increase must be held to no more than 2°C to 2.5°C above pre-industrial levels to avoid widespread, intolerable impacts on human well-being [2]. The ultimate objective of the framework climate change treaty is "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system … within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner" [3]. Climate change goals already adopted by some governments are stringent. For example, California has committed to reduce greenhouse gas emissions by 80% by 2050, and replace 10% of liquid transportation fuels with low-carbon fuels by 2020 [4].

Developed and developing countries alike will have to adopt radical solutions to achieve these emissions reductions. Current sub-national, national and international policy assumes that carbon sequestration, nuclear power, ocean fertilization, atmospheric aerosols, and other such technologies, which heretofore have been considered too novel or too dangerous to use, will have to be deployed at large scale, globally [5]. Yet it will be difficult to move forward with promising technologies that might preserve us from the consequences of global warming because they also pose potential hazards, promise uncertain benefits, and in some cases are already burdened with restrictive legislation and poor public image.

Elected officials, private investors, academic research scientists, nongovernmental organizations and government regulators will drive the choice of which technologies are pursued. They wield the instruments of innovation and dissemination: tax credits, grants, venture capital, intellect, public support, and regulatory carrots and sticks. They will research the effects and effectiveness of each new technology. They will weigh its economic, ecological, social and cultural value. The suggestions here are addressed to them, with the goal of improving technology policy choices by suggesting different approaches to consultation that will bring in new information and new actors.

These policy professionals and scientific experts should not and cannot act independently of the public. International law and domestic law have established the importance of public participation, particularly in matters of environmental risk [6]. By ratifying the Aarhus Convention, 42 nations committed to provide public notice and opportunity for effective participation in decisions regarding proposed activities that may have a significant effect on the environment [7]. However, the Aarhus Convention does not dictate who must be consulted, nor does it detail the modes of consultation that are most appropriate for a given context [8].

The past supplies the experience of DDT, a marvelous new pesticide whose harmful effects were long neglected until better communication brought about a more balanced policy approach to its use. Section 2 of this paper describes this example of the interplay between policymakers, scientists and the public. In the short history of biofuels and carbon sequestration, two of the newest and highly controversial technologies targeted at global warming provide examples of the risks of rapid commercialization. This discussion, in Section 3, describes the limitations of science and regulation when even the nature of possible harmful effects of these new technologies is uncertain. Risk assessment and cost-benefit analysis are the standard policy tools for this kind of problem; section 4 critiques excessive reliance either on narrow expertise or on the will of the general public. Rather than try to compensate by shifting authority from one set of actors to another, in section 5, this paper identifies the following strategies to improve access to information:

- Environmental assessment,[1] made more accessible
- Horizon scanning.
- Role of Human and Organizational Factors

Each of these approaches takes advantage of new research and modern information technology.

2. The example of DDT

DDT (dichloro-diphenyl-trichloroethane) offers the classic demonstration of a technology solution with traumatic consequences. A new pesticide proved highly successful at addressing serious agricultural and public health problems. Public policy decisions to disseminate the technology did not fully take account of relevant, available scientific information about harmful effects of wide-scale use. After many years of global use, the human, ecological and financial costs of using the pesticide were

[1] In this paper the term “environmental assessment” will be used, recognizing that many different terms are used and that some have special meaning. For example, the regulations implementing the environmental review requirements in the United States use environmental assessment to refer to a preliminary review that determines whether a full analysis, called an environmental impact statement, is required.

finally acknowledged. Stakeholders who affected the policy processes included industry, government and academic scientists, journalists, nongovernmental organizations, and the general public. The role of information – what information was available, to whom, when, and with what credibility – was key to the decision making process.

During World War II, DDT was discovered to be extremely effective in controlling insects that are vectors for malaria, typhus and other diseases. Further study and use of DDT showed that it was low cost, less toxic to humans than the alternatives available at that time, and that it had the added virtue of being highly persistent in the environment so that fewer applications were required [9].

After many years of widespread DDT use, Rachel Carson's 1962 book, *Silent Spring*, exposed the devastating effects of the pesticide on bird and fish reproduction to the general public [10]. Her book was based on a well-developed but obscure body of research and observation, the work of ornithologists, foresters and naturalists. This, plus additional evidence indicating that DDT was a potential carcinogen and a possible threat to human reproduction, a dramatic fish kill attributed to pesticides, and a lawsuit by Environmental Defense Fund succeeded in getting DDT taken off the market in the United States in 1972 [11]. Just one measure of the persistent, deadly and expensive legacy of DDT for society and the environment is the lengthy litigation over responsibility for cleaning up toxic chemicals from the seabed caused by the Montrose Chemical Company's disposal of DDT-contaminated waste into the Pacific Ocean (the old saying used to go "the solution to pollution is dilution") [12]. The defendants agreed to pay $140.2 million to settle the lawsuit [13].

As Kehoe and Jacobson recount, DDT was not deployed without recognition of its possible downside. During and after World War II, the government did extensive testing on DDT safety. Government scientists and the popular press warned that DDT's wide-spectrum toxicity and persistence could be "a two-edged sword" and might "upset the whole balance of nature" [9].

Despite these concerns, US production of DDT expanded from less than 200,000 pounds in 1943 to nearly 130 million pounds in twelve months of 1955-56 [9]. During this time, government regulators were alert to human health impacts, but they failed to take account of harm to wildlife or developing resistant strains of mosquitoes, because those were issues outside their regulatory mandate.

A noteworthy point in the DDT story is that there was sufficient information available to warn decision makers long before *Silent Spring*. In Cambridge, England, a pesticide manufacturer voluntarily treated its DDT-contaminated wastes before releasing them into the river that flows by one of the world's most prestigious universities, Cambridge University. "Disposal of untreated pesticide wastes into the [River] Cam would have represented a highly visible threat to a natural resource amenity greatly valued by influential members of British society," as Kehoe and Jacobson observe [9].

The story could end with the recognition that DDT's benefits were offset by unacceptable harms and stand as a warning against incautious deployment of new technology. However, the value of DDT as a tool to fight malaria, a disease that kills over 1 million people annually mainly in Africa, has never been equaled by safer alternatives. As a result, it is still used in over 20 countries for that purpose, using indoor spraying only [14]. The intensity of the controversy over this is highlighted by the fact that DDT is now one of the "dirty dozen" synthetic and highly toxic chemicals regulated internationally under the Stockholm Convention on Persistent Organic Pollutants (POPs Convention); it can only be used to control insects which transmit diseases like malaria and in the production of another pesticide [15].

In retrospect, it appears that DDT use could have been targeted to the applications that would yield the greatest benefits and that the harms of DDT use could have been limited by measures like those taken in Cambridge, England. Why did this not happen? From this account, better communication between experts from the fields of public health, wildlife biology, local and national government and the public (who valued songbirds over DDT) could have led to better use practices for DDT.

3. Controversies over two new technologies: biofuels and carbon sequestration

3.1. An agriculture-based energy supply: biofuels

Energy from plants has promised to solve pollution, energy security and energy poverty problems with a single technology. Biofuels are commonly made from crops like sugarcane, sugar beets, corn, wheat, oil palm, rapeseed, or soy. Because carbon dioxide emitted by biofuels is theoretically drawn from the air when the feedstock plant was growing, biofuels have the potential to provide liquid transportation fuels that have no or low net greenhouse gas emissions. However, lifecycle studies of biofuels production have shown that there are significant direct emissions of greenhouse gas from the feedstock production and fuel manufacture [16]. Subsequent studies indicate that indirect greenhouse gas emissions from land clearing, in response to the increased agricultural demand from energy crops, may nearly double greenhouse emissions over 30 years [17].

This discovery was an unfortunate surprise for policymakers who had been strenuously promoting biofuels [18]. In addition to the realization that biofuels might not actually reduce greenhouse gas emissions, concerns range from food scarcity due to competition of staple crops with energy crops; increased stress on sensitive wetlands, forests and scarce arable land; competition for water to irrigate energy crops; and impacts on biodiversity to labor and human rights issues, resulting from a push to supply the world's transportation fuel [19].

Numerous laws and other incentives for biofuels production have been put into effect. The European Union took early steps in this direction, setting national indicative targets for member States [20]. California is adopting a the Low Carbon Fuel Standard that will require 10% reduction in carbon intensity of liquid transportation fuels sold in California by 2020, creating a demand for low carbon fuels [21]. The proponents of the regulation assumed that biofuels would be an important component of the low carbon fuel supply [22]. What is surprising is that the poor result of the life cycle analysis for corn ethanol was predicted but was overtaken by politics that supported the corn industry. Information about the foreseeable ecological and social problems of biofuels was neglected while significant private and public investments were made and government policies were put in place.

3.2. "Clean coal"

Carbon sequestration is a technology or natural process that removes carbon dioxide from the atmosphere. In natural processes such as plant growth, plants metabolize and retain carbon until the dead plant decomposes and re-releases the carbon to the atmosphere. The field of artificial carbon sequestration includes research on seeding the ocean with iron to stimulate marine organisms to take up carbon dioxide from the atmosphere and geological sequestration, where carbon dioxide is injected into geological formations underground. This is commonly done with small volumes of carbon dioxide as a technique to manage oil and gas extraction, but the experience of sequestering large amounts of carbon dioxide underground in order to permanently remove it from the atmosphere has a limited history in Norway and a few other pilot projects elsewhere [23]. It is considered a useful technology to capture some of the carbon dioxide that is released when coal is used as an energy source. China, Germany, Poland and the United States are among the countries for which coal is an important component of their energy supply. Since coal remains a widely available and relatively inexpensive energy source, carbon capture and sequestration (CCS) is potentially a significant climate change technology [24].

Although US President Obama supports it, there is strong public opposition to CCS from some communities. Some believe that coal-dependent nations like the United States and Germany would make a faster transition from coal if CCS were not available. There are those in the environmental justice movement who are working to unburden communities of color from bearing a disproportionate share of dirty industries, with coal-fired power generation being a significant contributor to health problems. For both these groups, CCS solves only one of the urgent pollution problems associated with coal burning, while leaving coal-based energy as a threat to public and environmental health.

Another set of risks associated with CCS is insufficient information about the extent, type and nature of harm that could result from wide-scale deployment of sequestration technology. Possible risks include contamination of drinking water; accidental leakage of carbon dioxide; and seismic instability [25]. Elizabeth Wilson and colleagues suggest that the actual threat of harm is likely negligible:

> "Once injected, evidence from natural CO2 reservoirs and from numerical models suggests that CO2 can, in principle, be confined in geological reservoirs for time scales well in excess of 1000 yr and that the risks of geological storage can be small" [25].

On the other hand, large-scale failure of CCS projects, in terms of leakage, will be more damaging from a climate change perspective than not attempting it at all, for the following reason. Capturing and sequestering carbon requires the use of energy – with the concomitant GHG release – over and above that required by power generation or other purpose. This is what is called the "energy penalty" of CCS. It means that, if sequestration fails, *more* carbon dioxide will be released to the atmosphere than would have been produced by the initial activity alone.

The US public has had little opportunity to contribute to formal decision making about whether and how to proceed with CCS research, pilot testing and full-scale deployment. So far, a similar lack of information and participation in decision making about CCS seems to exist in the European Union [26].

4. Difficulty deciding: the experts and the people

The lack of a rational process of risk assessment and public decision making for selecting and deploying low-carbon technologies is likely to lead to a poor long-term outcome. We may fail to adopt useful technologies and suffer unnecessary GHG emissions or we may be careless and adopt a technology with severe, unforeseen side effects. The interplay between experts, appointed or elected official decision makers, and the public on whose behalf the decision is being made is critical.

Although the general topic is how we choose climate change technologies, the question must be re-framed as "how do we choose the risks that we are willing to accept?" For example, how do we weigh the possibility that carbon sequestration may contaminate groundwater with the possibility that a failure to use the technology might contribute to global warming impacts like sea-level rise of over one meter? For decisions without the vast uncertainties of these alternatives, methods like cost-benefit analysis, ecological risk assessment and environmental assessment are used to identify and compare relevant information. Cost-benefit analysis generally entails identifying and comparing the pros and cons of an activity; a more formal approach requires quantifying and assigning a monetary value to the pros and cons. Required by several laws in the United States, cost-benefit analysis may not include any public consultation. Environmental assessment identifies the environmental impact of a proposed action, positive and negative, and generally requires a comparison with alternative approaches which should include taking no action at all and public notice and comment [27].

Decision making distortions affect experts and non-experts alike, as has been amply demonstrated by social scientists. Applying their insights to climate and technology risk, we may discover that we perceive the risks of climate change quite differently than we perceive technology risks. This in turn may incline us to recoil from one alternative and accept another, and as we will see, this might lead to poor outcomes. Clearer understanding of the factors that can distort interpretation or lead us to overlook important data will not guarantee a perfect result, but it will improve the quality of analysis and choice in these highly uncertain and complex environments.

Traditional risk assessment and risk management is based on the notion of experts as the chief source of guidance for decision makers. Risk assessment is considered the more neutral, fact-based task; risk management is understood to be a political decision about governance [28]. One prominent academic proponent of technocratic decision making argues that the public "think poorly about dangers" [29]. In his view, the general public's flawed perception leads it to pressure government officials in favor of particular policies; government officials, responsive to the electorate, then proceed to ignore real risks and to waste resources on other, less important ones.

In classic comparisons of public risk calculation it is observed that people are willing to drive automobiles but refuse to live near a nuclear power plant, although the respective mortality statistics suggest that the car is more dangerous [29]. Like Mr. Spock of the Starship Enterprise, nuclear engineers are prone to say "this is not logical," relying on a calculated probability of a nuclear accident for their confidence [30]. The populist weighting of risk derives from several influences. Salient, vivid examples of negative outcomes stick in people's minds and influence their belief that it is more frequent or dangerous than it is. Acts of commission are viewed more negatively than omission. Some outcomes, like radiation poisoning, seem more horrible and are more feared than others. And people are apparently more willing to accept risks that are voluntary and over which they have control, like choosing to drive, than those over which they have no control, like the malfunction of a nuclear power plant. Other factors include fairness, procedural inclusiveness, morality, familiarity, and remoteness in time [31]. Peter Sandman usefully summarizes the factors at issue as "hazard" and "outrage." He says:

> "Call the death rate (what the experts mean by risk) 'hazard.' Call all the other factors, collectively, 'outrage.' Risk, then, is the sum of hazard and outrage. The public pays too little attention to hazard; the experts pay absolutely no attention to outrage. Not surprisingly, they rank risks differently" [32].

Distinguishing between experiential and analytic approaches to risk perception and management adds nuance. The tendency in the literature has been to associate the general public with experiential decision making, which is described as emotional. Decision making by experts is often considered more analytic, and thus more rational than the experiential approach. Deference to expert opinion is common, and the analytic approach is perceived to be more reliable. Examples are the expert view that nuclear power and genetic engineering have social benefits that far outweigh harm to public and environmental health, in contrast to public anxiety about the suffering that would result from radiation leaks and the unknown effects of genetically modified food - "Frankenfoods." Winickoff et al. argue that "Social science and regulatory experience instead emphasize that value judgments and public participation play an important role in generating reliable and conclusive risk assessments, especially in new and contested risk situations" like genetically modified foods [28].

While experts may be less subject to distortions in their decision making from heuristics that use stored personal experience (representativeness and availability heuristics) or the greater weight that non-experts give to downside risks, they may be prone to overconfidence in their judgments [33]. On the one hand, they have strong motivations to appear confident and accurate to themselves and to colleagues [34], and even experts have constraints on their attention that lead to confirmation bias and vulnerability to the proverbial, unanticipated, "flying cow" – the problem that it is difficult to know what we do not know [35]. As Dimitrov remarks, scientific information is "a product of social processes among scientists and other social actors" [36].

On the other hand, Weber observes that climate scientists give significantly greater weight to the dangers of global warming than the public does, because the scientists not only give greater weight to statistics and models of climate effects, but they have more personal experience observing effects like melting glacial ice and submerged islands [37].

A way out of these psychological traps is suggested by "multiattribute utility theory," which emphasizes communication and trust. Salient characteristics are the inclusion of multiple goals, minimization of goal conflicts, and recognizing that communication is binding because repeated interactions build or destroy trust. Operationalizing these involves framing situations in terms of social goals triggering the powerful need for social affiliation and social approval. Weber recommends employing scenario analysis to put experiential and affective processing and aversion to uncertainty to good use in planning for uncertain climate change outcomes. Weber also recommends combining analytic and experiential processes to improve interpretation of climate model results and to motivate responsive actions. Weber further advises influencing actions and choices with strategic framing of information to prime cooperation.

Finally, in situations of high complexity or novelty, there simply is not enough information for scientists to be considered fully informed experts. At the cutting edge of research, "[h]euristics (rules-of-thumb) replace direct observation and synthesis in guiding the formation of scientific consensus and introduce the possibility of multiple outcomes" [38].

Even those who assume that objectively sound decisions will result from the expert's analytic approach, public participation in risk management decisions is often recommended and frequently legally mandated. In some instances, the public may actually be expert – it may have information and informed judgments to contribute. The "public" may include all citizens, or the identity of participants might vary according to context. A core justification for public participation in policy is the fundamental understanding of democracy [39]. Even Sunstein sees a role for informed public deliberation, despite his suspicion of the "intuitions of interest groups and populism" [29].

This discussion leads us perforce to conclude that neither experts nor the public can provide a "correct" answer to complicated technology choice questions. Working together, pooling the different kinds of information that experts (whether from the academy, industry or government) and the general population possess, all of the potentially relevant information can be made available. Understanding the biases and distortions that can be traps for expert and popular judgment, rational but responsible opinions can be formed. There are many processes that can facilitate cooperative investigation and decision making. Techniques for collecting relevant information, bringing it to the attention of appropriate decision makers, and avoiding problems like information overload are constantly being sought by government officials, business and academic researchers. Some of these approaches are discussed in the following sections.

5. Information strategies

Missing a key element of a problem is a recurrent issue that is likely to arise with new energy, geoengineering and other climate change-related technologies. Difficult trade-offs may need to be made. As we saw in the case of DDT, policymakers focused on DDT as a low-cost, high performance solution to public health and agricultural problems while failing to evaluate DDT as an environmental health risk itself. Similarly, by focusing on the benefits of biofuels for energy security and for the agricultural sector, the European Union, the US, and the State of California overlooked a suite of potential costs. In swift succession, the international media, advocacy groups, and academic researchers published reports on the greenhouse gas performance and food security impacts of large-scale biofuel development. As a result, the prospect of avoiding something like the DDT catastrophe was vastly improved. The biofuel story suggests that modern communications, the engagement of civil society and unbiased contributions of the research community can produce better public policy on technology development and deployment. This section identifies three strategies that bring a range of perspectives and disciplines to bear, encourage repeated re-assessment, and use a systematic method to ensure that these steps are taken.

5.1. Environmental Assessment

Environmental assessments could make a significant contribution to the decision making process regarding potentially dangerous energy, albedo and carbon sink technologies by providing both varied sources of information and public voice. An environmental assessment identifies the ecological, social and economic consequences of a proposed activity, plan or program. The public may be given the opportunity to review and comment on the assessment at various stages of the process. Where environmental assessment is a legal requirement, the environmental assessment must be taken into account in determining whether the proposed activity may go forward. Environmental assessment is unusual because it is one of the few formal processes that brings very diverse opinions and expertise – from environmental professionals, advocates, self-selected citizens and government agencies – to bear on proposed activities. An environmental impact statement for a large-scale project can be a truly impressive compilation of data, politics and analysis [39].

Environmental assessment is by now a well-accepted, familiar approach [40] and indeed it is mandated in many domestic legal systems and international treaties [27][41]. Both customary international law [42] and the UN Framework Convention on Climate Change (UNFCCC) require environmental assessment. The UNFCCC states that parties shall

> "Take climate change considerations into account, to the extent feasible, in their relevant social, economic and environmental policies and actions and employ appropriate methods, for example impact assessments…with a view to minimizing adverse effects on the economy, on public health and on the quality of the environment, of projects or measures undertaken by them to mitigate or adapt to climate change" [3][42].

Nonetheless, the practice of environmental assessment varies widely across jurisdictions [43]. The threshold of environmental impact that triggers assessment, the type of projects covered, the extent of public access to information and public participation, the extent of true consideration of environmental assessments before decision is made and the existence of mandatory mitigation of harmful impacts are sometimes adequate and in other cases insufficient to provide effective assessment or true environmental protection. A hurdle is frequently political will. Every country that mandates environmental assessment experiences conflict over reluctance of authorities and project proponents to provide full, timely disclosure of information and effective consultation with other stakeholders.

Research projects and larger government research and development programs are not always subject to environmental assessment, even though the early stages of technological development are precisely when important investment decisions are taken. For example, the Aarhus Convention states that certain research, development and testing activities are exempt "unless they would be likely to cause a significant adverse effect on environment or health;" this exemption might be interpreted quite broadly [7].

Although in the US the National Environmental Policy Act (NEPA) does require environmental review for any federal action that significantly affects the environment, including research activities, a recent decision reversed course on assessing the overall research and development program for carbon sequestration technologies and practices. In 2004, the US Department of Energy (DOE) announced its intention to carry out a programmatic environmental impact assessment of the federal Carbon Sequestration Program, which at the time included 80 separate projects,

> "The Proposed Action is for DOE to continue implementation of its Carbon Sequestration Program with a focus on moving toward GCCI [Global Climate Change Initiative] goals and to eventually help meet the requirements of the Framework Convention on Climate Change. To achieve these objectives, the Program needs to consider, evaluate, develop, and implement carbon capture and carbon storage technologies, including effective measurement, monitoring, and verification methods, over a longer-range planning horizon. The Program also needs to provide technological viability data for the GCCI 2012 technology assessment" [44].

The Department of Energy proposed to "evaluate the issues and impacts associated with the demonstration and deployment of technologies to implement the key elements of the Program: carbon dioxide capture; sequestration (geologic, oceanic, and terrestrial); [Measurement, Monitoring, and Verification]; and breakthrough concepts" [44]. The alternatives that would have been examined included alternative technologies or variations in the mix of technologies, variations in the implementation of sequestration methods and variations in implementation by geographic region, as well as a "no action" alternative that would have been a more limited continuation of existing research. The assessment would have looked at impacts from the processing, land use effects of running pipelines, health and safety issues from instantaneous or slow leakage of carbon dioxide, socioeconomic and cultural impacts, effects on water resources and ocean chemistry and potential hydrologic fractures due to carbon dioxide injection that could harm aquifers or cause seismic events. As part of the scoping phase, the public was invited to attend explanatory meetings held in eight different sites around the country, and to comment on the issues to be addressed in the environmental assessment.

In 2007 the US DOE decided to cancel the programmatic environmental impact statement in favor of a project by project approach [45]. There are no doubt good reasons to prefer individual project assessments, but those would have been done in any case under the previous plan. The opportunity to identify a broader range of issues, to compare across geographic sites, and to scan for cumulative effects was lost by choosing to evaluate projects individually. There is even the possibility that smaller projects might not rise to the level of significance and would be overlooked entirely. The US biofuels research program has similarly devolved responsibility for environmental review to the facility or project level. Consequently, cumulative impacts have been assessed by researchers but not through the NEPA process.

A systematic, publicly accessible, flexible, low-cost archive of all environmental assessments, linked to maps would address the project by project approach along with other problems that erode the utility of environmental assessment. Though environmental assessments are rich sources of information, they are generally lost from history. One proposal is to create an internet-based, geographic information system (GIS)-linked repository of all environmental assessments [46]. The first step would preserve the value of millions of dollars invested each year in data, analysis and public input by putting all environmental assessments on the internet, ideally in a digital, searchable format. With historical data readily available, it would be possible to go back and evaluate the efficacy of mitigation and the accuracy of projections made by project proponents and opponents. Linking assessments to geographic information would facilitate cumulative impacts analysis, allowing easy viewing of projects in the same watershed or airshed, or affecting vulnerable human populations or particular species of concern.

Using environmental assessment to support decisions about climate change technology can be helpful, but to be really effective there need to be several reforms. Environmental assessment should be done at the research and development stage, and it should cover research programs that, as a totality, may have a significant impact on the environment. If research moves to field testing, re-assessment is needed, and it is needed again if the technology is scaled up since effects of scale and deployment in varied environments are very likely to have impacts that were not revealed in the lab or in field testing. Carbon sequestration presents this issue: pumping carbon dioxide into geologic strata has been used in oil and gas fields for many years, but it is recognized that much larger scale use of the technology in many different geological formations may have different consequences. Environmental assessments should be made available electronically at no cost as described for researchers to draw on and to inform the public, political debate.

5.2. Horizon scanning

Eyes looking in many directions, reporting emerging risks, are the goal of the many practices that comprise horizon scanning. They are based on the assumption that strategic planning requires a multitude of perspectives. Horizon scanning is particularly intended to identify low probability-high-impact events. The city-state of Singapore became interested in horizon scanning when, focused on the threat of post-9/11 terrorism, it was unprepared for the SARS epidemic; in 2005, the Risk Assessment and Horizon Scanning program was created [47]. Great Britain, the Netherlands and Switzerland have become interested in applying the basic techniques of horizon scanning to improve strategic planning in diverse domains. Horizon scanning is not a single approach, but rather a grouping of practices drawn from many disciplines: information technology, modeling, artificial intelligence and social networking may be used to work with data and human informants [48].

5.2.1. Singapore. Singapore's Risk Assessment and Horizon Scanning (RAHS) program "aims to provide policymakers with anticipatory knowledge of the nature of potential upcoming issues so that risks may be minimized and opportunities maximized" [49]. The Singaporean approach initially focused on strategic shocks that could affect national security based on experience of the 1997 Asian financial shock, political crises and terrorism. When 15 years of experience in scenario planning left the government unprepared to deal with the public health risk posed by SARS, it started to experiment with additional methods to improve awareness of threats across a 360 degree horizon and sensitivity to faint warning signals. A hallmark of the Singapore program is its emphasis on non-linear thinking as a source of resilience.

RAHS has developed a "whole-of-government" approach. While it emphasizes cross-agency collaboration in government and network building across professional academic and business communities, RAHS also uses powerful computing tools to link participants, provide data and carry out analysis. Detecting emerging trends is aided by the technology and by consultation with other government analysts within a closed network. The elements of the RAHS system are:

- Data collection and information organization;
- Context and scenario development using models that are constructed to understand and represent situations with an emphasis on context and structure;
- Monitoring and detection that allows the matching of incoming data to previously identified patterns or contents of interest;
- Pattern discovery and evaluation tools allow for the automated processing of data through natural language processing engines, as well as the visualization of information in order to aid the serendipitous discovery of new patterns;
- Collaboration, in terms of data, models, monitors and methods [47].

Singapore has been aggressive in pursuing fresh approaches that can be added to the developing body of horizon scanning practice. The belief is that "[t]he resultant diversity will reduce the possibility of getting blindsided by reliance on one particular approach or by one way of thinking about the future."

Although Singapore has opened up RAHS for its universities to study financial markets, agricultural commodities, public service, ethnic conflict and other topics, the approach is so strongly influenced by national security concerns that it may have limited application to the problem of low-carbon technology planning. Also, its planning horizon is only two to five years, while the planning horizon for new climate change-related technology must be on the order of decades.

5.2.2. Great Britain. In Britain, the Chief Scientific Adviser, currently Professor John Beddington, leads the Foresight Programme and its Horizon Scanning Centre to tackle sustainable energy and other topics that require strategic planning and risk assessment in highly complex, novel contexts. In such situations existing knowledge is not a sufficient guide to good decisions. One of the goals of the Centre is "[t]o spot the implications of emerging science and technology and enable others to act on them" [50]. Centre projects include a best practices guide for horizon scanning and two major projects, the Sigma Scan which explores future issues and trends that will face British public policy in the next 50 years and a scan on Wider Implications of Science and Technology [51]. The best practices guide recommends horizon scanning as a tool that can be used to review a broad spectrum of information beyond usual sources that is suitable for short to medium time horizons. The biodiversity scan, discussed below, provides an indicative example.

5.2.3. Biodiversity scan. A group of British scientists used horizon scanning to examine future threats to biodiversity in the United Kingdom within the next forty years, seeking to identify issues that were not already part of the public policy agenda [52]. Their goal was to identify all issues of potential future importance, a first step in planning policy. They looked for weak or conflicting signals of issues that are just beginning to emerge but that might become threats or opportunities in the future. The insight that faint signals that are observed in multiple contexts may be significant is drawn from horizon scanning, so consultation was designed to identify issues that persisted across disciplines by consulting informants from the natural sciences, social sciences, journalism and the field of horizon scanning itself.

Their method was relatively simple: representatives of government departments and non-governmental organizations (NGO) were invited to join academics, journalists and horizon scanning experts to prioritize, score, comment on and suggest additions to a list of issues. The original list was compiled from past horizon scans and other relevant government and NGO reports. Each issue was characterized by its potential benefits and threats, research needs, the likelihood it would occur and the level of threat that it posed. The project director recommends repeating the scan at 3-year intervals.

The biodiversity horizon scan placed in the top 25 of 195 issues geoengineering, demand for biofuels and increase in coastal and offshore energy generation, all potential technology responses to climate change and the type of technology with which this article is concerned. Each was scored as high likelihood, high threat to biodiversity. The horizon scan report identifies needs for further risk assessment and research into environmental impacts of geoengineering; more analysis of biodiversity and land use for biofuels crops; and the use of cost-benefit analysis and life-cycle analysis for offshore and coastal renewal energy development.

The report on the biodiversity horizon scan suggests several useful points. With regard to the horizon scan itself, the issues identified were found to be highly dependent on the people involved, yet the “challenge is to identify people who can give a broad view of developments in other fields” [52]. The project found it helpful to address this by including a mix of disciplines and by using other horizon scans as source material. Participants repeatedly identified a need to revise risk assessment to better include Earth system and ecological factors. They also asked for better monitoring of the natural environment to provide better early warning signals of adverse impacts.

5.3. Risk and the role of Human and Organizational Factors

A University of California, Berkeley research program is developing new tools to integrate technology with human factors in the context of environmental disasters, using insights from their studies of infrastructure failure and high reliability organization design [53]. These contexts are highly demanding, because system failure can so easily translate into catastrophe. The interdisciplinary research project initially came together in response to the Hurricane Katrina disaster. The team reported a set of recommendations that address the role of human and organizational error, drawn from their analysis of what occurred in New Orleans but capable of being generalized to other circumstances [54]. Their approach is of particular interest because it addresses the expert’s tendency to discount expertise in other domains, which Oppenheimer refers to as the "inhibitory effect of disciplinary walls" [55].

This research is seeking a systematic way of integrating qualitative and quantitative information to improve risk assessment and risk management in highly complex situations. Computer modeling and geographic information systems (GIS) are used to integrate information about individuals and social groupings with environmental data from sensors, field reports and remote sensing. The computer models that result will be able to identify broad trends [56].

This work has produced insights about valuable sources of information. Journalists and the electronic news media have an important role to play, as was also noted in the Biodiversity Horizon Scan described above. Although generally transparency is preferred, by providing access for anonymous informants to report, sensitive information can be collected. Drawing from the study of high reliability organizations, the group observed that by requiring incidents of failure to be reported—even if it had to be done anonymously—the reports could be scanned to identify patterns that could be used as early warnings of dangerous conditions.

Current work involves the adaptation of an assessment system that was designed for offshore oil platforms, commercial ships, oil and gas refineries, and pipeline systems to new problems, Quality Management Assessment System (QMAS), and System Risk Analysis System (SYRAS). Structures such as offshore oil platforms or levees are designed for factors like strength and capacity, but they may experience failures in operation or due to maintenance [57]. These failures are traceable to human error, with organizational roots. Reliability Assessment and Management for offshore structures builds on more than thirty years’ experience with both qualitative and quantitative analyses to detect and address potential problems in advance, learn from failure, and intervene during incidents to return the system to safe function.

Interactive assessment and management during the build-up toward a dangerous situation has the most to contribute to the problem of managing climate change and technologies. Society has already committed to developing technologies, so assessment can no longer be considered prospective; instead, problems will need to be identified and addressed as they arise. The problems that are likely to arise with offshore structures and technology development differ significantly in the time frame during which problems arise: hours versus months or years. However, they share the characteristics of complexity, uncertainty and novelty.

The basic procedure for the qualitative analysis is to periodically run an assessment with a team of experts from relevant disciplines, including people working within the system and outsiders. They identify factors of concern; interview stakeholders; develop scenario analysis based on information about the system and interviews with key individuals which allow for anonymous discussion if desired; score performance of system components (operators, organizations, interfaces, etc.); and propose mitigation of factors of concern that have been identified. In a technology setting, the group of stakeholders might be expanded beyond a specific facility to the industry and the people it affects. For carbon sequestration, this could include communities residing near sequestration sites; project managers, owners and employees; local, state or provincial, and federal regulators; seismologists, chemists, public health experts and ecologists.

The quantitative assessment evaluates the system's probability of failure and provides a tool to measure the effects of mitigation. For infrastructure systems failure is an objective event; technology policy will not be susceptible to similarly concrete definition of failure. However, the analytical framework might shed some light on the dimensions of performance for low carbon technology. For example, the life cycle phases of design, construction, operation and maintenance are relevant to carbon sequestration facilities; they might be further divided into research and development, pilot testing and full-scale deployment of the technology and considered with an industry-wide scope. The criteria of serviceability (carbon is actually reduced), safety (no public or environmental health problems), durability and compatibility (expected costs) are translatable. So is the recognition that failures derive from both intrinsic and extrinsic causes. The first are "factors such as extreme environmental conditions and other similar inherent, natural, and professional uncertainties" while extrinsic causes are human and organizational factors.

A sensitive point in applying the QMAS/SYRAS system to the very different technology context is the mathematical link between the qualitative and quantitative assessments, which was calibrated with historical data about structural failure and success. An analogous calibration would be difficult to perform. This highlights a distinction between the complicated but perhaps knowable context of structural failures, the complex context of technology development, and the chaotic climate system. The reliance on historical patterns of system failure or success in the QMAS/SYRAS approach suggests that the system is more knowable, less uncertain than either projections of climate change or the development of new low carbon technologies.

Bea emphasizes that the most important factor in a QMAS/SYRAS review is the people carrying out the assessment. Good selection of the right people for the task is important, in terms of training, experience and motivation. Teams should include a variety of backgrounds and experience and should be trained in techniques to mobilize the necessary awareness, skills and knowledge when called for. Training and retraining to refresh skills are necessary for individuals and teams.

This system provides a number of tools and a systematic approach to analyzing complex interfaces between people, the environment and technology. Perhaps the computer models and calculations can be converted into a tool to analyze climate change technologies. In any case, the work that has been done to create and demonstrate QMAS/SYRAS underscores three points:

- the value of bringing a wide spectrum of expertise to bear on the assessment;
- the need to train the assessors in a common group process to improve their communication with each other; and
- the importance of iterative assessments and follow-up assessment of mitigation.

6. Conclusion

Successful adoption of innovative GHG emission-reduction solutions calls for innovation in policy analysis. This paper has suggested new risk assessment, participation and decision support tools that can be used to evaluate urgently needed technologies to manage the threat of dangerous climate change. Uncertainties about geo-engineering, carbon sequestration, biofuels, and other technologies need to be reduced where possible, accounted for through democratic processes, and reevaluated over time. The great epidemiologist, Sir Austin Bradford Hill, pointed out that although we can act only on the information we have, however imperfect, we have an obligation to make timely decisions in the light of the information we *do* have [1]. In recent years, environmental assessment, horizon scanning and human and organizational factors research have evolved to help identify the information that we have, to account for the uncertainties that remain, and to support decisionmaking by bringing information and analysis to the attention of policymakers.

Multiple perspectives are essential to provide information from relevant disciplines and to represent the gamut of stakeholders likely to be affected. While environmental assessment does this well by systematically evaluating the proposed activity from different perspectives, government agencies responsible for assessment should make better use of the internet to preserve studies and analyses that have been done and to communicate with stakeholders during the assessment process. Horizon scanning programs have been very successful in taking advantage of social networking and other information technologies to collect and integrate knowledge and opinions from research, government, and civic communities. Singapore's continuous innovation and its use of powerful computing are noteworthy in this regard. Projects like the British biodiversity scan show that it can be scaled up or down in terms of cost, complexity and number of participants. When horizon scanning is integrated into government practice, it can be turned into a more or less continuous process. The British approach, looking out forty years in some cases, takes a long-term view well-suited to the needs of climate policy and acknowledges the need for repeating horizon scans at frequent, regular intervals to monitor significant change.

As observations throughout research, pilot testing and deployment phases reveal new information about innovative energy, carbon sink and albedo technologies, and as the effects of climate change and other features of the planet alter over time, such regular re-assessment can be provided by repeated environmental assessments or horizon scans. The QMAS/SYRAS process, if suitably adapted, adds techniques to investigate and learn from failures. Here, the recognition that failures derive from both intrinsic and extrinsic causes calls attention to the changing external environment on the one hand and the human process of technology development and deployment on the other.

Timeliness is a key factor: risk assessment must be undertaken early in the technology development process, as decisions about allocation of resources and regulation should be taken in light of the best projections of benefits to be obtained and downside risks to be managed. In the case of DDT, it was only after years of widespread use that attention was paid to the environmental health impacts of the pesticide. The high level of attention paid by the international research, policy and media communities to the development of biofuels as a low-carbon liquid fuel enabled fairly early review and awareness of the need for correction in public policy. An example of the kind of alternatives review that would be helpful in the early stage of development is the original programmatic environmental impact assessment of the federal Carbon Sequestration Program. It would have provided exactly the kind of information that is needed to support the difficult choices of where to invest and what regulation will be necessary, including the important evaluation of cumulative effects of all the projects in the program.

Communication about risk with the public is a necessary (though not sufficient) step to gaining public acceptance. Jeffrey Sachs of Columbia University's Earth Institute identifies public acceptance and carefully crafted regulatory controls as two factors so critical to the success of carbon capture and sequestration technology that a failure on one or the other "could kill the technologies" [58]. Formal environmental assessment requires this kind of public participation, inviting the public to review and comment on the assessment and, in principle, taking the public comment into account in the final decision. Vigorous use of these strategies is necessary now.

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References

[1] Phillips C V and Goodman K J 2004 The missed lessons of Sir Austin Bradford Hill *Epidemiologic Perspectives & Innovations* **1** 3 (quoting Hill AB 1965 The environment and disease: association or causation? *Proc R Soc Med* **58** 295-300.)

[2] Raven P H, Bierbaum R M, Holdren J P, MacCracken M C and Moss R H 2007 *Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable* (Research Triangle Park, NC: Sigma Xi: and Washington DC: United Nations Foundation) xi.

[3] *United Nations Framework Convention on Climate Change*, Article 2 (1992).

[4] *Cal. Exec. Order No. S-3-05* 2005 (establishing 2010, 2020 and 2050 targets for California to reduce greenhouse gas emissions);
California Global Warming Solutions Act of 2006 (AB 32) Cal. Health & Safety Code §§ 38,500–38,599 (committing California to reduce greenhouse gas emissions to 1990 levels by 2020);
Cal. Exec. Order No. S-01-07 2007 (establishing the California Low Carbon Fuel Standard).
Cal. Air Resources Bd., *Climate Change Proposed Scoping Plan*, 2008.

[5] Holdren J P 2008 AAAS Presidential address: science and technology for sustainable well-being *Science* **319** 424, 429-31;
Crutzen P 2006 Albedo enhancement by stratospheric sulfur injections: a contribution to resolve a policy dilemma? *Climatic Change* **77(3-4)** 211-219 (Proposing to artificially enhance earth's albedo and thereby cooling climate by adding sunlight reflecting aerosol in the stratosphere);
Stafford N 12 July 2006 Should we flood the air with sulphur? *Nature* news@nature.com [viewed 29 June 2009] (describing negative responses to Crutzen's proposal).

[6] Bernasconi-Osterwalder N 2008 Transparency, participation and accountability in international economic dispute settlement *Sustainable Development in International and National Law: What Did the Brundtland Report Do To Legal Thinking and Legal Development, and Where Can We Go From Here?* eds Bugge H C and Voigt C (Groningen:Europa Law Publishing);
Payne CR 1998 Local regulation of natural resources: efficiency, effectiveness, and fairness of wetlands permitting in Massachusetts *Environmental Law* **28** 519.

[7] *Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters*, 25 June 1998, reprinted in 38 *ILM* 517 (1999), http://www.unece.org/env/pp [viewed 29 June 2009].

[8] The guide to the convention advises on best practice: Stec S and Casey-Lefkowitz S 2000 *The Aarhus Convention: An Implementation Guide* (New York & Geneva : United Nations).

[9] Kehoe T and Jacobson C 2003 Environmental decision making and DDT production at Montrose Chemical Corporation of California *Enterprise & Society* **4(4)**.

[10] Carson R 1962 *Silent Spring* (Boston : Houghton Mifflin & Cambridge, MA : Riverside Press).

[11] *Federal Environmental Pesticides Control Act* (21 October 1972) (A US Environmental Protection Agency history of DDT further notes that by 1972 DDT use had decreased significantly due to increased insect resistance and availability of more effective alternatives as well as public concern over safety.);
EPA 1975 *DDT Regulatory History: A Brief Survey (to 1975)* (US EPA History Office).

[12] *Consent Decree with Montrose Chemical Corporation of California et al., United States and State of California* v. *Montrose Chemical Corporation*, No. CV 90-3122-R (C.D. Western

IOP Conf. Series: Earth and Environmental Science **8** (2009) 012001 doi:10.1088/1755-1315/8/1/012001

Div. Calif., March 15, 2001), http://www.darrp.noaa.gov/southwest/montrose/admin.html [viewed 1 July 2009].

[13] NOAA, General Counsel for Natural Resources, Office of Habitat Conservation, Office of Response and Restoration, Southwest Region, http://www.darrp.noaa.gov/southwest/montrose/index.html, [viewed 24 May 2009].

[14] World Health Organization 2006 Indoor Residual Spraying. Use of indoor residual spraying for scaling up global malaria control and elimination *WHO Position Statement Series 1112* (World Health Organization, Geneva); Jackson D C 2009 Malaria, DDT, and desperation in Uganda *Boston Globe* (Boston).

[15] *Stockholm Convention on Persistent Organic Pollutants* 22 May 2001 40 *I.L.M.* 532;
Provisional DDT Register pursuant to Paragraph 1, Part II of Annex B, http://chm.pops.int/Programmes/DDT/DDTregister/tabid/456/language/en-US/Default.aspx [viewed 1 July 2009].
Division of Toxicology 2002 *Public Health Statement - DDT, DDE, and DDD* ed. US Agency for Toxic Substances and Disease Registry (Describing human and environmental health effects of DDT exposure).

[16] Farrell A E, Plevin R J, Turner B T, Jones A D, O'Hare M, Kammen D M 2006 Ethanol can contribute to energy and environmental goals *Science [Reports]* **311** 506-08.

[17] Searchinger T, Heimlich R, Houghton R A, Dong F, Elobeid A, Fabiosa J, et al. 2008 Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change *Science* **319** (5867) 1238-40.
Letter responses to Searchinger et. al.'s paper entitled Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change *Science Online* 2008, http://www.sciencemag.org/cgi/eletters/319/5867/1238 [viewed 1 July 2009].

[18] Commission of the European Communities 1 Oct 2007 *Report on the progress made in the use of biofuels and other renewable fuels in the Member States of the European Union* (Brussels) (Report acknowledges that indirect land use change could alter the otherwise favourable greenhouse gas emissions from biofuels).

[19] UN-Energy 2005 *The Energy Challenge for Achieving the Millennium Development Goals* (United Nations).

[20] Directive 2003/30/EC on the promotion of the use of biofuels or other renewable fuels for transport (OJ L 123, 17.5.2003, p. 42);
Directive 2003/96/EC restructuring the Community framework for the taxation of energy products and electricity (OJ L 283, 31.10.2003, p. 51).

[21] California Low Carbon Fuel Standard Regulation 2009 (California Air Resources Board Resolution 09-31).

[22] Payne C R 2009 Local meets global: the low carbon fuel standard and the WTO *N.C. J. Int'l L. & Comm. Reg.* **34(Spring)** 891-917.

[23] Intergovernmental Panel on Climate Change 2005 *Special Report on Carbon Capture and Sequestration*;
International Energy Agency 2007 *Near-Term Opportunities for Carbon Dioxide Capture and Storage* (Paris : International Energy Agency).

[24] Schiermeier Q 2008 Europe to capture carbon *Nature [News]* **451** 232.

[25] Philibert C, Ellis J, Podkanski J 2007 *Carbon Capture and Storage in the CDM* (Organisation for Economic Co-operation and Development, Paris : International Energy Agency).
Wilson E J, Johnson T L, et al. 2003 Regulating the ultimate sink: managing the risks of geologic CO2 storage *Environmental Science and Technology* 3476-3483.
World Resources Institute 2008 *CCS Guidelines: Guidelines for Carbon Dioxide Capture, Transport, and Storage* (Washington, DC).

[26] Anderson J, Chiavari J, De Coninck H, Shackley S, Sigurthorsson G, Flach T, et al. 2009 Results from the project ‘Acceptance of CO2 capture and storage: economics, policy and technology (ACCSEPT)’. *Energy Procedia* **1** 4649-53.
Johnsson F, Reiner D, Itaoka K, Herzog H. 2009 Stakeholder attitudes on carbon capture and storage - an international comparison *Energy Procedia* **1** 4819-26.
[27] 42 U.S.C. § 4332(2)(c) *US National Environmental Policy Act of 1969*, Pub. L. No. 91-190, Sec. 83 Stat. 852 (1970) (codified as 42 U.S.C. §§ 4321-4347), [NEPA].
40 CFR 1500-1508, Council on Environmental Quality Regulations for Implementing the Procedural Requirements of NEPA, July 1, 1986.
U.S. Environmental Protection Agency 1998 *Guidelines for Ecological Risk Assessment*.
[28] Winickoff D, Jasanoff S, Busch L, Grove-White R and Wynne B 2005 Adjudicating the GM food wars: science, risk, and democracy in world trade law *Yale J. Int’l L.* **30** 99.
[29] Sunstein CR 2002 *Risk and Reason* (Cambridge).
[30] Kunreuther H and Slovic P 1996 The process of risk management: science, values and risk *The American Academy of Political and Social Science Quarterly* **545** 116.
[31] Kuran T, Sunstein CR 1999 Availability cascades and risk regulation *Stan. L. Rev.* **51**:683, 708-9.
[32] Sandman P M 1987 Risk communication: facing public outrage *EPA Journal* 21-22.
[33] Oppenheimer M, O'Neill BC, Webster M 2008 Negative learning *Climatic Change* **89**:155-72, 156.
[34] Latin, H 1988 Good science, bad regulations, and toxic risk assessment *Yale J. on Reg.* **5** 89, 129 (“the majority of interveners in regulatory proceedings are sponsored by affected industries or trade associations, which means the scientific performance of agency officials will regularly be monitored and challenged by industry scientists who advocate less conservative risk assessment practices. Agency bureaucrats, like other people, are sensitive to criticism and may deliberately or subconsciously seek to placate persistent critics.”).
[35] Ossorio P N 2001 Pills, bills and research shills: physician-researchers’ conflicts of interest *Widener L. Symp. J.* **8** 76, 88-91 (explaining the role of judgment in scientific research, the potential for unconscious bias, and illustrating the negative effect on expert judgment when professional reputation, financial gain, and other interests conflict).
[36] Dimitrov R S 2006 *Science & International Environmental Policy* (Lanham, MD : Rowman & Littlefield Publishers, Inc.).
[37] Weber EU 2006 Experience-based and description-based perceptions of long-term risk: Why global warming does not scare us (yet) *Climatic Change* **77**:103-20, 108.
[38] Atik J 1996-1997 Science and international regulatory convergence *NW. J. Int'l L. & Bus.* **17** 736, 748.
[39] Ebbesson J. 2007 Public Participation in *The Oxford Handbook of International Environmental Law* eds Bodansky D, Brunée J, Hey E. (Oxford: Oxford University Press) pp 682-703.
[40] Principle 17, Rio Declaration, 31 *ILM* 874 (1992); endorsed by UN General Assembly Res. 47/190 (1992) (“Environmental impact assessment, as a national instrument, shall be undertaken for proposed activities that are likely to have a significant adverse impact on the environment and are subject to a decision of a competent national authority”).
[41] EC Directive 97/11/EC, 3 March 1997 amending Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment OJ No. L 073, 14/03/1997 P. 0005.
Convention on Environmental Impact Assessment in a Transboundary Context, in force 10 September 1997, 30 ILM 802 (1991) (Espoo Convention).
1994 Energy Charter, Art. 19.
[42] Sands P 2007 *Principles of International Environmental Law, 2d ed.*

IOP Conf. Series: Earth and Environmental Science **8** (2009) 012001 doi:10.1088/1755-1315/8/1/012001

Bastmeijer K, Koivurova T. 2000 Introduction *Theory and Practice of Transboundary Environmental Impact Assessment* eds Bastmeijer K, Koivurova T, (Ithaca: Cornell University Press) pp 1-25, 3-8.

[43] Dalal-Clayton B, Sadler B 2005 *Strategic Environmental Assessment: A Sourcebook and Reference Guide to International Experience* (Earthscan).

[44] *Notice of Intent to Prepare a Programmatic Environmental Impact Statement for Implementation of the Carbon Sequestration Program* 2004 69 Fed. Reg. 21514.

[45] *Notice of Cancellation of Programmatic Environmental Impact Statement for Implementation of the Carbon Sequestration Program* 2007 72 Fed. Reg. 8363.

[46] Farber D. 2007 Bringing Environmental Assessment into the Digital Age. *Taking stock of environmental assessment : law, policy and practice* ed Holder J, McGillivray D (Routledge-Cavendish).

[47] Tan Hong Ngoh, Edna and Hoo Tiang Boon eds 2008 *Thinking about the Future: Strategic Anticipation and RAHS* (Singapore: National Security Coordination Secretariat, S. Rajaratnam School of International Studies).

[48] Helft M 2008 Google uses searches to track flu's spread *New York Times* (analysis of frequency of searches for terms like “flu symptoms” in Google and Yahoo may provide early warning of regional flu outbreaks).

[49] RAHS Singapore, http://rahs.org.sg/t2_home.html, [viewed 29 June 2009].

[50] Foresight Horizon Scanning Centre. http://www.foresight.gov.uk/Horizon%20Scanning%20Centre/index.asp [viewed 5 July 2009].

[51] Government Office for Science 2009 *The Sigma Scan* http://www.sigmascan.org/Live/Home.aspx [viewed 29 June 2009];
Foresight Horizon Scanning Centre undated *Wider Implications of Science and Technology (WIST) Programme: Report of Findings*.

[52] Sutherland W J, Bailey M J, Bainbridge I P, Brereton T, Dick J T A, Drewitt J and et al. 2008 Future novel threats and opportunities facing UK biodiversity identified by horizon scanning *Journal of Applied Ecology* **45(3)** 821-833.

[53] Center for Catastrophic Risk Management, at University of California, Berkeley. The author is an affiliate of the Center.

[54] Farber D A, Bea R G, Robers K, Wenk E, Inkabi K, 2007, Reinventing flood control, *Tulane Law Review* **81** 1-43.

[55] Oppenheimer M O'Neill, B C and Webster M 2008 Negative Learning. *Climatic Change* 89:155-172. (Oppenheimer describes how disciplinary silos may have delayed progress on understanding the process of ozone depletion and may still be affecting research on the effects of global warming on the West Antarctic ice sheet).

[56] Bea R G, Mitroff I, Roberts K H, Farber D and Foster H, 2008, *A new approach to risk: the implications of E3* (Berkeley : Center for Law, Energy and the Environment).

[57] Bea R G, 2002, Human and organizational factors in reliability assessment and management of offshore, *Risk Analysis* **22(1)** 29-45.

[58] Sachs J D 2008 Keys to climate protection: Dramatic, immediate commitment to nurturing new technologies is essential to averting disastrous global warming *Scientific American* April 2009.