Impacts of Climate Change

At first global warming sounded like a good idea, especially to people in Northern climes. But starting in the 1960s, scientists recognized long-range problems, concentrating at first on sea-level rise and a threat to food supplies. New items were gradually added to the list, ranging from the degradation of ecosystems to threats to human health. Experts in fields from forestry to economics, even national security experts, pitched in to assess the range of possible consequences. It was impossible to make solid predictions given the complexity of the global system, the differences from one region to another, and the ways human society itself might try to adapt to the changes. But by the start of the 21st century, it was clear that climate change would bring serious harm to many regions—some more than others. Indeed many kinds of damage were already beginning to appear. (This essay does not try to cover the entire history of impact studies, but sketches some examples. Current scientific understanding of impacts is summarized at the end).

Through the first half of the 20th century, when global warming from the greenhouse effect was only a speculation, the handful of scientists who thought about it supposed any warming would be for the good. Svante Arrhenius, who published the first calculations, claimed that nations like his native Sweden "may hope to enjoy ages with more equable and better climates."[1] Most people assumed that a "balance of nature" made catastrophic consequences impossible, and if any change did result from the "progress" of human industry, it would be all to the good. In any case nobody worried about the impacts of a climate change that scientists expected would only affect their remote descendants, several centuries in the future, if it happened at all.

A few scientists took a closer look in the late 1950s when they realized that the level of carbon dioxide gas (CO_2) in the atmosphere might be rising, suggesting that the average global temperature might climb a few degrees Celsius before the end of the 21st century. Roger Revelle, the most senior of these researchers, publicly speculated that in the 21st century the greenhouse effect might exert "a violent effect on the earth's climate" (as *Time* magazine put it). He thought the temperature rise might eventually melt the Greenland and Antarctic icecaps, raising sea level enough to flood coastlines. Noting that climate had changed abruptly in the past, perhaps bringing the downfall of entire civilizations in the ancient world, in 1957 Revelle told a Congressional committee that the greenhouse effect might someday turn Southern California and Texas into "real deserts." He also remarked that the Arctic Ocean might become ice-free, to Russia's advantage. Everyone understood this was all speculation, more science fiction than scientific prediction. Another senior scientist, more cautious, told his colleagues that they should take seriously the possibility of "warming, and possible changes in rainfall and cloudiness" by the early 21st century. Meanwhile a pair of graduate students reported that the CO_2 greenhouse

[1] Arrhenius (1908), p. 63.

effect "could raise such problems as coastal flooding due to rise in sea level and increased aridity in certain areas."[1]

More scientists began to look at the matter after 1960, when observations showed the level of CO_2 in the atmosphere was indeed rising rapidly. In 1963 a path-breaking meeting on "Implications of Rising Carbon Dioxide Content of the Atmosphere" was convened by the private Conservation Foundation. "Conservation" was the traditional term for a movement that was developing into "environmentalism," centered on the growing realization that human activities had expanded to the point where they could damage vital ecosystems on a global scale. Participants in the meeting began to frame greenhouse warming as an environmental problem—something "potentially dangerous" to biological systems as well as to humans.

The meeting set the pattern for many later exercises. It brought together experts in carbon dioxide and climate (in fact the *only* experts at that time: Gil Plass and Dave Keeling) with a handful of experts in fisheries, agriculture and so forth. And it resulted in a "consensus" report, which warned that if fossil fuel burning continued, "the earth will be changed, more than likely for the worse." But the group, like many later ones, admitted ignorance, and called for more research. They could scarcely say what dangers might await a century ahead. They suspected forest productivity would improve, which did not sound bad, and that the distribution of species including commercial fisheries would change, which could be bad or good. The only thing they felt confident about was that rising temperatures would increase melting of the world's glaciers, raising the sea level and bringing "immense flooding" of low-lying areas.[2]

Global warming caught the attention of the U.S. President's Science Advisory Committee. In 1965 they reported that "By the year 2000 the increase in atmospheric CO_2 ... may be sufficient to produce measurable and perhaps marked changes in climate..." Without attempting to say anything specific, they remarked dryly that the resulting changes "could be deleterious from the point of view of human beings."[3] The following year, a panel of the U.S. National Academy of Sciences warned against "dire predictions of drastic climatic changes." Dire predictions of one or another climate catastrophe had in fact been a staple of the popular press for decades, as magazines, books and other media peddled colorful speculations of every variety. The Academy

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[1] Time (1956). Real deserts: Revelle in United States Congress (85:2), House of Representatives, Committee on Appropriations, *Report on the International Geophysical Year* (Washington, D.C.: Government Printing Office, 1957), pp. 104-106. Ice-free: see note near end of this essay. Lloyd V. Berkner, "Horizons of Meteorology," talk to American Meteorological Society and American Geophysical Union, May 1, 1957, Am. Met. Soc. records, Box 12; my thanks to Alan Needell for this information. "Such problems": Wallace Broecker and Bruno Giletti writing in the student magazine *Yale Scientific* in 1957, according to Broecker and Kunzig (2008), p. 71.

[2] Conservation Foundation (1963), pp. 1, 5, 14. They also speculated (p. 6) that "many life forms would be annihilated" in the tropics if emissions continued unchecked for several centuries, a time too far away to mean much to anybody.

[3] President's Science Advisory Committee (1965), pp. 126-27.

panel remarked that the geological record showed swings of temperature comparable to what the greenhouse effect might cause, and "although some of the natural climatic changes have had locally catastrophic effects, they did not stop the steady evolution of civilization."[1]

That was not entirely reassuring. Concern grew among the few scientists who paid attention to climate theories. Meanwhile the rise of environmentalism was raising public doubts about the benefits of human activity for the planet; smoke in city air and pesticides on farms were no longer tokens of "progress" but instigators of regional or even global harm. A landmark study on "Man's Impact on the Global Environment," conducted at the Massachusetts Institute of Technology in 1970, suggested that greenhouse warming might bring "widespread droughts, changes of the ocean level, and so forth," but could not get beyond such vague worries.[2] A meeting in Stockholm the following year came to similar conclusions, and added that we might pass a point of no return if the Arctic Ocean's ice cover disappeared. That would change the world's weather in ways that the scientists could not guess at, but that they thought might be serious. Their main point in bringing up the Arctic ice, however, was simply to illustrate "the sensitivity of a complex and perhaps unstable system that man might significantly alter."[3]

Up to this point, scientists expected that greenhouse warming, if it happened at all, would bring no serious impacts until well into the 21st century. And the 21st century seemed so far away! But was climate change really so distant? In the early 1970's the world saw vivid illustrations of climate fluctuations as savage droughts afflicted the American Midwest, devastated the Russian wheat crop and brought starvation upon millions in Africa. Studies of climate were still in their infancy, and scientists were debating whether the greenhouse effect from CO_2 emissions might be overwhelmed by the cooling caused by other forms of pollution. A few scientists speculated that industrial emissions of aerosols might cause severe cooling, while others suspected that natural cycles might bring a new ice age within the next few centuries. Nobody knew whether warming or cooling was more likely.

Studies of the impacts of climate change therefore tended to address generalities such as how a given type of crop would respond to either a rise or a drop in temperature. An example was a 1974 report commissioned by the U.S. Central Intelligence Agency (CIA). What if the climate altered radically within a few decades—perhaps the sudden freeze that some journalists warned might grip the planet? The report concluded that the entire world's food supply might be imperilled. There would be mass migrations, perhaps even wars as starving nations fought for the remaining resources. Scientists scoffed at the scenario, for none of them expected a radical climate shift, whether warming or cooling, could come so swiftly. But for a more distant future, the grim speculations could not be entirely dismissed.

Governments were now putting some of the environmental movement's demands into law; that created a practical need for formal "environmental impact" assessments. A new industry of

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[1] National Academy of Sciences (1966), Vol. 2, "Research and Development," p. 88.

[2] SCEP (1970), p. 18.

[3] Wilson (1971), pp. 17, 182.

expert consultants strove to forecast effects on the natural environment of everything from building a dam to regulating factory emissions. On a broader scale, people concerned about the environment applied increasingly sophisticated scientific tools to study the impacts of deforestation, acid rain, and many other large-scale activities. They looked at impacts not only on natural ecosystems but on human health and economic activities. Assessing the long-term impact of greenhouse gases fitted easily into this model.

One example was a 1977 report on "Energy and Climate" from a panel of geophysicists convened by the U.S. National Academy of Sciences. By this time the speculations about cooling had faded away, while many scientists felt that greenhouse warming was a strong possibility. The panel got fairly specific about the potential consequences. On the positive side, the Arctic Ocean might eventually be opened to shipping. On the negative side, there would be "significant effects in the geographic extent and location of important commercial fisheries... marine ecosystems might be seriously disrupted." Stresses on the polar ice caps might lead to a surge of ice into the sea, bringing a "rise in sea level of about 4 meters within 300 years." As for agriculture, there would be "far-reaching consequences" which "we cannot specify... We can only suggest some of the possible effects. A few of these would be beneficial; others would be disruptive." There could be terrible "human disasters" like the recent African droughts. However, the panel made clear they could not foresee what might actually happen. They concluded vaguely that "world society could probably adjust itself, given sufficient time and a sufficient degree of international cooperation. But over shorter times, the effects might be adverse, perhaps even catastrophic."[1] Two years later another Academy panel said much the same, and took brief note of an additional threat—the rise of CO_2 in the atmosphere would make the oceans more acidic. Here too they found the consequences beyond guessing. Overall the experts could only conclude that as the world warmed, "the socioeconomic consequences may well be significant, but... cannot yet be adequately projected."[2]

Economists and social scientists were just beginning to take an interest in the topic. In 1980 the Academy appointed an "Ad hoc Study Panel on Economic and Social Aspects of Carbon Dioxide Increase," the first semi-official attempt to address these aspects directly, separate from the science. The panel's lame conclusion was that any problems would come so slowly that they would be overtaken by unpredictable technological and social changes. At worst, people who found themselves in a region with worsening climate could migrate to a better place, as had often happened in the past. This was supposed to be reassuring.

As studies proliferated, the topic of "climate impact studies" was starting to look like a respectable field of research. The significant reports of the late 1970s had all been American, and many scientists wanted to internationalize impact studies. An attempt was initiated by the International Council of Scientific Unions (ICSU), the United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO)—the march of acronyms signals the increasing levels of complexity and bureaucracy that were coming into play. However, a one-week meeting in Villach, Austria, in 1980 did not get any farther than the

[1] National Academy of Sciences (1977), pp. 8-14.

[2] National Academy of Sciences (1979), pp. 3, 24-27.

earlier U.S. Academy studies, and its report was not widely circulated. "The 'internationalisation' of the assessment effort was not very successful," admitted one of the leaders, Bert Bolin. A more substantial team effort, assembled in Stockholm, again reached the same conclusions as the American panels—global warming would have profound consequences for ecosystems, agriculture, water resources, the sea level and so forth.[1]

More categories of impacts emerged, each attracting its own little band of specialists. For example, an elaborate 1983 study by the U.S. Environmental Protection Agency, with more than 100 reviewers, studied sea-level rise. The experts concluded that by the end of the 21st century they "could confidently expect major coastal impacts, including shoreline retreat... flooding, saltwater intrusion, and various economic effects." A big step forward was a 1983 U.S. Academy report, the most detailed assessment up till then. It not only included familiar categories like agriculture and sea-level rise, but also pointed out that an increase in extreme summer temperatures would worsen the "excess human death and illness" that came with heat waves. Also, melting of permafrost in the Arctic could require adaptations in engineering. Also, climate shifts "may change the habitats of disease vectors." Finally and most important, "In our calm assessments we may be overlooking things that should alarm us." For there might be effects that no expert could predict or even imagine, effects all the more dangerous because they would take the world by surprise. Nevertheless the Academy, as usual, did not recommend any actual policy initiatives, aside from the scientists' customary plea for more research.

Meanwhile, in 1982 Bolin spoke about an international effort with Dr. Mustafa Tolba, the dynamic executive director of UNEP. Tolba, a former professor of biology at Cairo University, wanted to go beyond physical climate studies to bring attention to global ecosystems. That was the sort of "environmental" study that UNEP could support. Later WMO was brought in, and ICSU agreed to publish the results to help them become widely read. The resulting 560-page report, Bolin was proud to say, brought the greenhouse problem "much more to the forefront in the scientific community than earlier assessments had done, particularly amongst those engaged in analysis of the terrestrial ecosystems." The sequel was a 1985 UNEP/WMO/ICSU conference in Villach, energetically chaired by Tolba, which further publicized the scientists' warnings. The assembled experts went on to call for policy initiatives—not to restrict greenhouse gases, to be sure, but at least to mobilize an internationally coordinated effort to study policy options.[2]

The studies to this point had used a simple cause-and-effect model. Physical scientists would run computer models to predict changes in precipitation and the like. Others would follow by calculating immediate consequences, for example using historical records to predict how crop yields would vary with the weather. But if farmers could no longer get good results from corn, wouldn't they plant something more suited to their new climate? During the 1980s, some impact

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[1] Ad hoc panel: Oreskes et al. (2008b), p. 124; Bolin (2007), p. 34.

[2] Hoffman et al. (1983) as cited by Oreskes et al. (2008b), pp. 134-35, see also pp. 140-41. National Academy of Sciences (1983), pp. 45, 50, 53, on pests see also pp. 405-07. This followed a preliminary report, National Research Council (1982). Here and below I draw especially on Long and Iles (1997). They identify the first World Climate Conference (Geneva, 1979) as "the first major conference to address human health" (p. 8). Bolin (1986), pp. 35-38.

studies began to take account of how humans might adapt to climate change. By the end of the decade, some studies were linking models of crop responses with economic models. Complex interactions were no less crucial in natural ecosystems. Life scientists began to calculate how forests, coral reefs and so forth might respond to the rise of greenhouse gases. For example, could tree species move their ranges poleward fast enough to keep up with the temperature rise? At a still higher level of complexity, some studies began to account for the way one type of climate impact might interact with another.

These more sophisticated approaches guided the first comprehensive official U.S. government report, ordered up by Congress from the Environmental Protection Agency. The EPA's findings continued the trend toward predicting more numerous and more specific kinds of damage. The experts concluded (as summarized by *New York Times* in 1989) that "Some ecological systems, particularly forests... may be unable to adapt quickly enough to a rapid increase in temperature... most of the nation's coastal marshes and swamps would be inundated by salt water... an earlier snowmelt and runoff could disrupt water management systems... Diseases borne by insects, including malaria and Rocky Mountain spotted fever, could spread as warmer weather expanded the range of the insects." Some of this was already vaguely grasped by the minority of people who followed scientific news closely. Other predictions, notably the expansion of diseases, had been mentioned in passing before but were only now coming under detailed discussion.[1]

Studies of how climate change might affect human health expanded particularly swiftly in the 1990s, catching the attention not only of experts but the public. Here as in some other categories, the work was increasingly supervised not by a particular government but by international organizations, from the venerable World Health Organization to the new International Panel on Climate Change (IPCC, established 1988). Yet here as in some other categories, it was becoming clear that global generalizations were of little value compared with studies at a regional level. For example, insect vectors of tropical diseases like dengue fever and malaria (which already affected half a billion people) would expand their ranges. The main impacts would be felt in developing nations, but people in the developed world tended to worry chiefly about how such diseases might spread to the temperate zones.[2]

Any regional analysis had to start with the climate changes that would result from a given level of greenhouse gases, as calculated by computer models. But although the increasingly sophisticated models had come to a rough agreement on global features like the rise of average temperature, they differed in the details. In places where many factors balanced one another, for

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[1] Philip Shabecoff, "Draft Report on Global Warming Foresees Environmental Havoc in U.S.," *New York Times*, October 20, 1988, reporting on draft of United States, Environmental Protection Agency (1989). My search of the Google news archive at http://news.google.com/archivesearch/ found that newspaper and news magazine items on disease spread by climate change and the threat to water supplies from earlier snowmelt began to appear in 1988-89. Items on impacts on water supplies due to the disappearance of glaciers started appearing only in 1997. Harm to water supplies was noted, for example, by Revelle and Waggoner (1983).

[2] Long and Iles (1997), pp. 29-33.

example the Sahel region between the Sahara desert and the African rain-forest, one model might predict a benign increase of rainfall and another, terrible droughts. Policy-makers did not much care about the average global temperature—they wanted to know how things would change in their own locality.

Unable to make quantitative predictions of just what might happen in each region, the IPCC decided to study "vulnerabilities," that is, the nature of damage that a given system might sustain from any of the likely sorts of climate change. This was in line with an established practice of vulnerability studies in many other areas, from food supplies to earthquakes. The experts also considered benefits, but the very term "vulnerability" showed that by now most of them believed the net effects of greenhouse warming would be harmful. Some disagreed, leading to a serious controversy during the discussions leading to the IPCC's initial report of 1990. The eminent Russian climatologist Mikhail Budyko argued, on the basis of his reconstruction of climates in the distant past, that warming would have important benefits. For Siberia, at least, he had a point—so long as the warming did not soar higher than in the earlier interglacial epochs he had studied. In the usual IPCC fashion, the experts papered over their disagreements, inserting some polite phrases accepting that there could be beneficial results in some northern locales.

The IPCC got much farther in 1997 with a pioneering report on "The Regional Impacts of Climate Change." Each region of the globe got its own detailed account of vulnerabilities. At this level it was obviously necessary to consider not only the local climate and ecological systems, but also the local economic, social and political conditions and trends, drawing in the social sciences as equal partners with geophysics and biology. It was becoming a standard practice to consider how people might adapt. For example, the panel concluded that Africa was "the continent most vulnerable to the impacts of projected changes." That was not just because so many parts of Africa were already water-stressed, subject to tropical diseases, and so forth, but still more because population pressure and political failings were causing environmental degradation that would multiply the problems of climate change. Above all, Africa's "widespread poverty limits adaptation capabilities." By contrast, the carefully managed agricultural systems of Europe and North America might even contrive to benefit from a modest warming and rise in the level of CO_2 (which could act as a fertilizer for some crops), although the developed nations would certainly suffer some harmful impacts as well.[1]

An elaborate assessment exercise that the U.S. government pursued in the 1990s took a different approach. The authors displayed, side by side, the results of two separate computer models (one constructed in the United Kingdom and one in Canada). In some regions the model predictions agreed; there seemed little doubt, for example, that Southern California would get a lot drier. In other regions they diverged, as when one model projected more rain in the Southeast and the other, less. Overall, the American experts agreed with the IPCC that highly managed ecosystems of farming and forestry might do quite well in the first half century of serious warming. On the other hand, nothing could prevent damaging changes in some natural ecosystems and expensive difficulties along the coasts. As for threats to health, there would be some problems but "adaptation is likely to help protect much of the U.S. population." And finally, "some aspects

[1] Budyko: Bolin (2007) p. 64. Watson et al. (1997), quote p. 6

and impacts of climate change will be totally unanticipated," which people could interpret optimistically or pessimistically, according to taste.[1] Scientists in another major industrial country, chilly Russia, foresaw even less worrisome results from global warming. These assessments, and the publics they addressed, could see the impacts as manageable because they were looking no more than half a century or so ahead. The 22nd century was so far away! Surely by then, humanity would have taken control of its emissions so that CO_2 would not rise to three or four times the pre-industrial level... wouldn't we?

The future state of the climate would depend crucially on what emission controls nations chose to impose. That exposed a problem with the standard way of predicting impacts. Scientists had tried to look into the future by extrapolating the visible trends and forces along a single line, calculating a most likely outcome within a range of possibilities: "global average temperature will rise three degrees plus or minus 50%" or the like. People would then estimate the consequences of a three-degree rise.

Professional "futurologists" in the social sciences, and the policy-makers they advised, had abandoned that method of prediction decades earlier, when they realized that most of their predictions had been far off the mark. They turned to an approach practiced by military planners and wargamers since the 1940s: instead of trying to predict the most likely future, imagine a wide range of possible futures, and for each of these develop a detailed "scenario". The aim was to stimulate thinking about how your operations should be structured so they would hold up under any of the likely contingencies. This approach was applied to environmental questions in the 1970s by studies that sketched out a set of very different possible futures for pollution, exhaustion of natural resources, food production and so forth, depending on just what policies governments might adopt.[2] Since the 1980s most corporations and government agencies had used scenarios for their planning.

The IPCC had taken up this approach from the outset, assembling experts to write scenarios in a lengthy intergovernmental process. The result, published in 1992, was a set of six different scenarios, each describing a way that the world's population, economies, and political structures might evolve over the decades. Experts in various fields of physical and social science could try to figure how much of each of the various greenhouse gases would be emitted by the society of a given scenario, then compute the likely climate changes, and then estimate how that society would try to adapt. Much was omitted from these scenarios, not least the feedback by which climate changes might affect the socio-economic system and thereby the emissions themselves. A second try in 1996 produced no fewer than 40 different scenarios, grouped into families in terms of rate of economic growth, sensitivity to environmental problems, degree of international cooperation and so forth.[3] There were so many unknowns, and so many differences from region

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[1] National Assessment Synthesis Team (2000-2001), quotes p. 9

[2] The influential pathbreaker was Meadows et al. (1972).

[3] J. Leggett et al., "Emissions Scenarios for the IPCC: an Update," in IPCC (1992), pp. 68-95. The scenarios are available at http://sedac.ciesin.org/ddc/is92/. 1996: IPCC Special Report on Emissions Scenarios, online at http://www.grida.no/climate/ipcc/emission/

to region with each region demanding its own detailed study, that the small community of researchers could explore in depth only a few of the possibilities. Many research projects used only one scenario, a middle one with emissions neither sharply restricted nor rising explosively.

In its own reports, the IPCC not only laid out clearly the range of scenarios it had investigated, but got increasingly specific about whether the consensus of experts judged a given impact to be "likely," or "very likely," or "virtually certain." There was plenty of uncertainty, not least because the laborious studies lagged behind the science; the panel's 2001 impact assessments relied on older computer model results that were derived from the still older 1992 emission scenarios. (It was only around 2009 that the impacts community figured out ways to work through the different stages in parallel rather than sequentially.)[1] In the panel's 2001 and 2007 reports, the most impressive parts resembled the earlier reports that simply laid out a variety of the likely direct impacts, and suggested which regions would be especially vulnerable.

Scholars who studied the two-decade series of IPCC assessments reported a clear trend toward more complex and interdisciplinary analysis, in which climate impacts were combined with other stresses and with potential adaptations. The trend responded to the evolving needs of policy-makers. The scientists' first goal had been to evaluate the overall danger to the world associated with a given level of greenhouse gases, in order to advise governments how much effort they should make to restrict emissions. By the time that question was answered, greenhouse gases had risen to a level where some serious impacts were inevitable. Leaders in governments and business organizations were now asking for detailed and precise assessments so they could shape policies for adapting to the changes.[2]

The scientists' attempts at precision could be misleading. For example, studies published from the 1970s into the mid 1980s estimated that by 2100, the sea level might rise anywhere from a few tenths of a meter to a few meters. The upper limit dropped to about half a meter in the IPCC's 1995 report, and it stayed there in later reports. But in fact, the range of scientific estimates on how high the seas could rise in the 21st century remained broad. The rise would exceed a meter if polar ice sheets began to surge into the oceans in the next few decades. Most scientists had always considered that quite unlikely, but there were always some who argued that it was possible. The IPCC gave scant attention to such impacts that did not seem at least fairly likely to happen, even if they would be catastrophic in the event they did befall us.

This was different from the practice in many other kinds of impact studies. For example, the building codes of cities in earthquake zones, and evacuation plans for people living near nuclear reactors, dealt with problems that might have less than one chance in a hundred of happening in the next century or two. The IPCC, by contrast, was preoccupied with impacts that were more likely than not.

There were still people arguing that climate change would be beneficial. These included a few scientists and a large number of conservatives, amply funded by right-wing private American

[1] Moss et al. (2010), including an impacts studies historical timeline.

[2] Füssel and Klein (2006).

institutes. For example, a Hoover Institution publication held that "Global warming, if it were to occur, would probably benefit most Americans." There would be lower heating bills and other energy savings, and besides, "More people die of the cold than of the heat." Many asserted, as a Heartland Institute publication declared, that "More carbon dioxide in the air would lead to more luxuriant crop growth and greater crop yields." Little if any hard analysis backed up such statements, but there was some truth in them. As Russians in particular noticed, a bit of warming would bring some benefits to cold regions. But even in those regions the people, crops and entire ecosystems would eventually suffer more harm than good, according to the voluminous and detailed studies worked up by teams of economists, epidemiologists, agronomists and other experts. The public, however, scarcely knew that these teams existed and never read their reports. The experts' conclusions reached ordinary people at most as a summary paragraph or two in a news story, perhaps "balanced" by a statement from one of the institutions committed to denying any problem existed. Meanwhile some media featured exaggerated warnings of doom. "Global heating will all but eliminate people from the Earth," exclaimed a well-known scientist; a high-ranking bank officer declared that inaction on emissions would bring "the extinction of the human race."[1]

Reality descended upon the abstract world of impact studies as actual consequences of global warming began to appear. In the late 1990s, field surveys of sensitive and well-studied groups like birds and butterflies found them measurably shifting their ranges, or even facing extinction, in just the ways that could be predicted from the observed warming.[2] In the early years of the 21st century, instead of future possibilities some experts began to estimate the role that global warming might have played in one or another actual disaster. It turned out that because of unexpected complexities, the rich nations were not as safe as some had thought. One example: in 2003 a heat wave of unprecedented scope killed tens of thousands in Europe. Nobody had foreseen that old people could not save themselves when the traditional August vacation emptied the cities. Another example: bark beetles, no longer controlled by winter freezes, devastated millions of acres of forests from Alaska to Arizona, leaving the weakened timber prey to an unprecedented outbreak of forest fires. Nobody had prepared for this particular impact of global warming. By 2010 a world-wide increase in record-breaking and devastating heat waves, droughts and floods had convinced many insurance companies and ordinary citizens that something unprecedented was happening to the weather.

A description of impacts meant little to people unless it was translated into specific human terms. For example, if an aquifer turned brackish as the sea level rose, exactly what difference would that make to anyone? Since the early 1970s, economists had been developing increasingly detailed projections of the economic benefits and costs of global warming, working up from

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[1] Conservative quotes from McCright and Dunlap (2000), pp. 514-15. Lovelock (2009), p. 6; Kevin Parker, global head of Deutsche Bank Asset Management, quoted in John M. Broder, "Climate Deal Likely to Bear Big Price Tag," *New York Times* Dec. 9, 2009.

[2] Landmark studies included Parmesan (1996), finding a latitude shift in a North American butterfly (Edith's Checkerspot) and attributing it to climate change, and Parmesan et al. (1999) with "the first large-scale evidence of poleward shifts in entire species' ranges" from Europe.

regional examples to global estimates. Of course, it was not easy to put a dollar value on longer summers or the destruction of the world's coral reefs. In response to environmentalist warnings, a few free-market economists worked up calculations that found negligible costs from climate change, and warned that taxing or regulating emissions would wreck the economy. Others replied with calculations that gave opposite results. Economic analysis took off in the early 1990s with increasingly numerous and sophisticated studies.[1]

The most influential skeptical work came from Bjørn Lomborg, a Danish political scientist who wrote a best-selling book and in 2004 assembled a panel of prominent economists to analyze various approaches (the "Copenhagen Consensus"). Lomborg and his panel argued that it would be far better for humanity to spend its money on immediate problems like malaria than on long-term problems like global warming—although they did say that governments would do well to spend far more money on research on ways to reduce greenhouse emissions.[2] The debate evolved into a discussion of basic principles, exposing issues that the public and policy-makers scarcely appreciated. Some economists pointed out that the conventional methods of their field were not framed to deal with such an issue, where the main consequences were many years ahead and might bring anything from discomfort to devastation. Hardly any impact study looked farther ahead than 2100; the 22nd century just seemed too far away.

Governmental and international bodies stepped in, supporting elaborate professional studies. An outstanding example was the *Stern Review on the Economics of Climate Change*, produced for the British government in 2006 by Nicholas Stern, former chief economist of the World Bank, with a staff of 20. Stern framed the question in a businesslike "risk management" manner, studying the worst case plausible enough to be worth buying insurance against (under the assumption that the well-being of future generations had significant value for us in the present). His team calculated that if global warming in the 21st century was in the upper range of what scientists thought likely, the direct effects would cut the annual Global Domestic Product by some 5%. Indirect effects might possibly raise that as high as 20%, equivalent to the Great Depression of the 1930s or the damage in one of the 20th century's world wars—maintained perpetually. The economists made a rough estimate of the cost of preventing that, most likely a modest 1% reduction in Global Domestic Product. (The IPCC's 2007 report reached a similar conclusion.) "Climate change," Stern concluded, "is the greatest market failure the world has ever seen."[3]

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[1] Discussions began with D'arge and Kogiku (1973), arguing that CO_2 emissions should be restricted, and Nordhaus (1974), saying the greenhouse effect should not constrain energy growth in the near future at least. Long and Iles (1997) point to the U.S. Department of Transportation's Climatic Impact Assessment Program (aimed not at the greenhouse effect but aircraft emissions) for producing, in 1975, "the first assessment to focus on social and economic measures," (p. 6) and the 1989 U.S. Environmental Protection Agency study as "the first extensive appearance of an economic analysis of impacts."

[2] Lomborg (2001); Lomborg (2004), see also Lomborg(2007).

[3] Stern (2006) , p. 3. All these numbers were highly uncertain; Stern's estimated cost of stabilizing CO_2 at a level he thought reasonably safe (550ppm) might be anywhere from 3.5% of

There was an even more sobering way to frame climate change—as a security threat. For half a century, forward-looking military officers had considered with increasing concern what global warming might mean in their area of responsibility. They would surely be called upon, for example, if weather disasters multiplied. In 2003, defense intellectuals in the Pentagon commissioned a report on "An Abrupt Climate Change Scenario and its Implications for United States National Security." As reported in a leak to the press, the authors warned of a risk that "mega-droughts, famine and widespread rioting will erupt across the world.... abrupt climate change could bring the planet to the edge of anarchy as countries develop a nuclear threat to defend and secure dwindling food, water and energy supplies." The authors concluded that "the threat to global stability vastly eclipses that of terrorism." The report was strikingly similar to the CIA report prepared three decades before (see above). Again the specific "worst-case"scenario, an abrupt change in ocean circulation, was something scientists considered extremely unlikely. By now, however, impact studies had sketched out a range of more plausible scenarios that looked bad enough. If you thought like a military officer, the IPCC's approach—concentrating on what everyone could agree was likely, while ignoring less likely but still possible scenarios—was not "conservative" at all, but irresponsible. Many well-informed military officers and other national security experts, along with many political leaders and a majority of the world's public, now believed that the possible impacts of global warming ranked among the most dangerous long-term risks that civilization faced. [1]

GDP to -1% (net benefit), p. xiv. IPCC (2007e), and check the IPCC website http://www.ipcc.ch for subsequent reports. Criticism by economists, much of it technical, centered on Stern's use of a "0% discount." That bestowed as much value on costs to all later generations as costs to ourselves, and could be used to justify almost any expense. But the critics' preferred discounting, say at 3-4% per year, assumed the world economy was certain to expand indefinitely without a hitch—our grandchildren would be so fabulously wealthy that they could solve any problem, even as the environment deteriorated around them. And it ignored prudent insurance-style evaluation of the cost of altogether catastrophic impacts that scientists thought unlikely but entirely possible: a "fat tail" probability distribution, see Weitzman (2007), Weitzman (2009).

[1] In 1956 a leading scientist speculated that in a distant future we might "find that the Arctic Ocean will become navigable... If the Russian coastline increases by something like 2,000 miles or so, the Russians will become a great maritime nation." Testimony of Roger Revelle, U.S. Congress, House 84 H1526-5, Committee on Appropriations, *Hearings on Second Supplemental Appropriation Bill (1956)*, pp. 474 and 473. (See also note on submarines in "Government" essay.) Already in the 1970s, a couple of studies like the CIA study noted above had framed global warming as a security problem. Environmentalists since the early 1970s had argued more generally that the world would be more secure if it spent less money on military defense and more on defense against pollution and other environmental dangers. The groundbreaking 1988 Toronto Conference concluded that changes in the atmosphere were a major threat to global "security," and for climate change in particular the "ultimate consequences could be second only to a global nuclear war." For all this see Barnett (2001), who gives the quote from World Meteorological Organization (1989). Report for Pentagon: Schwartz and Randall (2003), reported by Stipp (2004); quote: Mark Townsend and Paul Harris, "Now the Pentagon Tells Bush: Climate Change Will Destroy Us," *The Observer,* February 22, 2004. An internet newspaper archive search will show, e.g., the Science Advisor to UK Prime Minister

What do we know about the impacts of global warming? A large body of scientific studies, exhaustively reviewed, has produced a long list of possibilities. Nobody can say that any of the items on the list are certain to happen. But the world's climate experts almost all agree that the impacts listed below are *more likely than not* to happen. For some items, the probabilities range up to almost certain.

The following are the likely consequences of warming by a few degrees Celsius—that is, what we may expect if humanity manages to begin restraining its emissions soon, so that greenhouse gases do not rise beyond twice the pre-industrial level. Without strong action the doubling will come well before the end of this century, bringing the planet to temperatures not seen since the spread of agriculture. By 2007, many of the predicted changes were observed to be actually happening. (For details see the IPCC and USGCRP impacts reports.[1])

*** Most places will continue to get warmer,** especially at night and in winter. The temperature change will benefit some regions while harming others—for example, patterns of tourism will shift. The warmer winters will improve health and agriculture in some areas, but globally, mortality will rise and food supplies will be endangered due to more frequent and extreme summer heat waves and other effects. Regions not directly harmed will suffer indirectly from higher food prices and a press of refugees from afflicted regions.

*** Sea levels will continue to rise for many centuries.** The last time the planet was 3°C warmer than now, the sea level was at least 6 meters (20 feet) higher.[2] That submerged coastlines where many millions of people now live, including cities from New York to Shanghai. The rise will probably be so gradual that later generations can simply abandon their parents' homes, but a

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Tony Blair, Sir David King, calling climate change "the greatest threat facing mankind" and "worse than terrorism." See report issued in 2007 by a group of retired three- and four-star admirals and generals: CNA corporation (2007), and report of a 2007 conference of academics and serving officers, Pumphrey (2008). At the request of Congress, in 2008 the CIA weighed in officially with a classified report declaring climate change had a "potential to seriously affect U.S. national security interests." Siobhan Gorman, "Report Says U.S. Security Faces Challenges From Global Warming," *Wall Street Journal*, June 25, 2008, online at http://online.wsj.com/article/SB121439562868003087.html. The first substantial appearance of climate change in a top-level U.S. military policy document was in the 2010 Quadrenniel Defense Review, worrying about both political instability and disaster response. In 2007, 64% of all Americans felt that their country was "in as much danger from environmental hazards, such as air pollution and global warming, as it is from terrorists:"Yale Center for Environmental Law and Policy: www.yale.edu/envirocenter.

[1] IPCC (2007) summarizes knowledge as of mid 2006. The 2007 Impacts Report is online at http://www.ipcc.ch/SPM13apr07.pdf, for latest results see http://www.ipcc.ch. For regional changes in the United States see the U.S. Global Change Research Program reports at http://globalchange.gov/. For a good popular account see Lynas (2007). Note that reviews such as Grassi (2000) have been only modestly revised by more recent work.

[2] Kopp (2009).

ruinously swift rise cannot be entirely ruled out. Meanwhile storm surges will cause emergencies.

*** Weather patterns will keep changing** toward an intensified water cycle with stronger floods and droughts. Most regions now subject to droughts will probably get drier (because of warmth as well as less precipitation), and most wet regions will get wetter. Extreme weather events will become more frequent and worse. In particular, storms with more intense rainfall are liable to bring worse floods. Some places will get more snowstorms, but most mountain glaciers and winter snowpack will shrink, jeopardizing important water supply systems. Each of these things has already begun to happen in some regions.[1]

*** Ecosystems will be stressed,** although some managed agricultural and forestry systems will benefit, at least in the early decades of warming. Uncounted valuable species, especially in the Arctic, mountain areas, and tropical seas, must shift their ranges. Many that cannot will face extinction. A variety of pests and tropical diseases are expected to spread to warmed regions. These problems have already been observed in numerous places.

*** Increased carbon dioxide levels will affect biological systems** independent of climate change. Some crops will be fertilized, as will some invasive weeds (the balance of benefit vs. harm is uncertain). The oceans will continue to become markedly more acidic, gravely endangering coral reefs, and probably harming fisheries and other marine life.

*** There will be significant unforeseen impacts.** Most of these will probably be harmful, since human and natural systems are well adapted to the present climate.

The climate system and ecosystems are complex and only partly understood, so there is a chance that the impacts will not be as bad as predicted. There is a similar chance of impacts grievously worse than predicted. If the CO_2 level keeps rising to well beyond twice the pre-industrial level along with a rise of other greenhouse gases, as must inevitably happen if we do not take strong action soon, the results will certainly be worse . Under a "business as usual" scenario, recent calculations give even odds that global temperature will rise 5°C or more by the end of the century—causing a radical reorganization and impoverishment of many of the ecosystems that sustain our civilization.[2]

All this is projected to happen to people who are now alive. What of the more distant future? If emissions continue to rise for a century—whether because we fail to rein them in, or because we set off an unstoppable feedback loop in which the warming itself causes ever more greenhouse gases to be evaporated into the air—then the gases will reach a level that the Earth has not seen since tens of millions of years ago. The consequences will take several centuries to be fully realized, as the Earth settles into its new state. It is probable that, as in the distant geological eras with high CO_2, sea levels will be many tens of meters higher and the average global temperature

[1] For North America, see Karl et al. (2008).

[2] Sokolov et al. (2009); for a summary see MIT News Office press release, May 19, 2009, at http://web.mit.edu/newsoffice/2009/roulette-0519.html

will soar far above the present value: a planet grossly unlike the one to which the human species is adapted.

> *What can people do about global warming, and what should we do? See my Personal Note and Links.*

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